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Aerial Surveys of Endangered and Protected Species in the *EMPRESS II* Ship Trial Operating Area in the Gulf of Mexico

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Aerial surveys were conducted from November 1991 to June 1992 in an 81.5 × 110 km area approximately 50 km south of Mobile, AL. Line transect methods were used to estimate abundance of sea turtles and cetaceans over a 6-month period (November to April). Sonograms and spectrograms of cetacean vocalizations proved useful for species identification. Passive acoustical methods were employed to determine the presence of cetaceans beneath the surface.

Three species of sea turtles (*Dermochelys coriacea, Caretta carotta, Chelonia mydas*) and at least four species of toothed whales (*Gobicephela macrorhynchus, Delphinus delphis, Tursiops truncatus, Stenella* spp.) were observed and/or recorded in the area. In addition, sperm whales (*Physeter catodon*) were recorded south of the area. A total of 83 sea turtle sightings and 116 cetacean sightings were made in the area during the 6-month study. Most sea turtles were observed as singles, whereas dolphins were generally found in groups of 2 to over 100. Sea turtle density was estimated to be 0.01 turtles/km^2; cetacean density was estimated at 0.78 odontocetes/km^2. Densities of both sea turtles and cetaceans were less than what has been reported for other areas of the northern Gulf of Mexico. An adjustment factor, based upon acoustic data, of 1.3 is suggested as a correction factor for submerged cetaceans.

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CONTENTS

AERIAL SURVEYS OF ENDANGERED AND PROTECTED SPECIES IN THE *EMPRESS II* SHIP TRIAL OPERATING AREA IN THE GULF OF MEXICO

INTRODUCTION

In the territorial waters of the United States, sea turtles and cetaceans are protected. All five species of sea turtles found in the Gulf of Mexico are listed as either threatened or endangered, and all whales and dolphins are protected under the Marine Mammal Protection Act of 1972. Information on the distribution and abundance of these species in the coastal waters of the northern Gulf of Mexico is limited; although, there has been a recent interest in studying the area (Schmidly 1981; Mullin 1988; Lohoefener et al. 1990; Mullin et al. 1990, 1991; Jefferson et al. 1992).

Odontocetes (toothed whales) are active sound emitters with relatively high source levels. They probably spend at least 75% of their time beneath the surface, making passive acoustic detection a valuable method of determining their presence. Conversely, marine turtles cannot be detected acoustically, since they do not emit sound.

Unfortunately, the near-shore waters of the north-central Gulf of Mexico are, for the most part, a high ambient noise shallow-water environment. Snapping shrimp (*Alpheus* spp. and *Synalpheus* spp.), large ships, and geological survey vessels in the area complicate the acoustic environment causing difficulties in detecting marine mammal sonic emissions in several frequency bands.

The primary purpose of this study was to determine the abundance of sea turtles and marine mammals in the *Empress II* ship trial operating area during the period from November 1991 to April 1992 (see Fig. 1). The northern border of the study area was located approximately 50 km south of Mobile, Alabama. The study area encompassed the "ALT 2" ship trial operating area, which was selected by the Navy as the preferred site for testing susceptibility of ships to electromagnetic pulses. Additional flights were flown until June 1992 to test methods and equipment for subsequent studies. We also investigated the feasibility of using passive acoustic detection techniques to locate and identify whales and dolphins in shallow coastal waters. It was hoped that passive acoustic systems could be employed to augment visual methods for censusing cetaceans throughout the year.

METHODS AND MATERIALS

A twin-engine Cessna 337 was used for all aerial surveys. The plane was equipped with navigational aids (Global Positioning System (GPS) and loran-C); [illegible] GPS was monitored by an on-board computer. Acoustic and water temperature vs. de[illegible]ata were acquired remotely. Expendable sonobuoys and Airborne Expendable Bathyt[illegible]graphs (AXBTs) were manually deployed from the door of the aircraft, and received signals [illegible] recorded on a specially modified sonobuoy receiver. Acoustic data were recorded on a digital audio tape recorder and AXBT data on a laptop computer.

The AN/SSQ-41B sonobuoy is a remote, lightweight, expendable VHF-FM radio link sensor that allows remote passive detection of underwater sound emissions. Each sonobuoy weighs approximately 7.5 kg and measures 12 cm in diameter and 91 cm in length. The AN/SSQ-41B consists of a subsurface hydrophone and preamplifier, a cable assembly, seawater battery pack, and surface electronics including a VHF transmitter and antenna (Fig. 2). The battery is activated by

seawater following deployment from the aircraft. The sonobuoys have an acoustic frequency range of 10 Hz to 10 kHz with a sensitivity of 116 ±2 dB relative to 1 μPa at 100 Hz (Fig. 3). This is equal to a ±19 kHz carrier deviation. Various depth and operating life settings are available. During this study a depth of 18 m and a life of 1 h were usually chosen.

The AN/SSQ-36 AXBTs are packaged similar to the sonobuoys. These expendable units consist of a thermistor temperature probe that, after deployment, drops at a rate of 1.52 ms to determine temperature vs. depth (Fig. 4).

Transmissions from the sonobuoys and AXBTs were received on the AN/ARR-52A sonobuoy receiver, which consists of four VHF-FM radio receivers, two preamplifiers, and four isolation amplifiers. The receiver was mounted in the aircraft on a specially designed equipment rack that also contained a power supply, an indication panel, and a radio set control. The entire receiver set operates on 28 vdc aircraft power and was capable of simultaneous reception on any 4 of 31 sonobuoy transmit frequencies in the 162.25 to 173.50 MHz frequency band. Sonobuoy data were recorded on a Sony TCD-D3 digital tape recorder with a frequency response of 20 Hz to 20 kHz ±1.0 dB. Signals from the AXBTs were transmitted to the sonobuoy receiver and recorded on a laptop computer.

Recorded sounds were loaded into a Macintosh SE/30 computer and analyzed for amplitude vs. time and power spectra. Additionally, sonograms of relative amplitude vs. frequency and time were produced.

Acoustical Studies

In order to determine how far deployed sonobuoys could detect marine mammals and therefore to have some idea of area covered acoustically, it was necessary to determine the following:

(a) expected acoustic paths;

(b) transmission loss;

(c) source levels; and

(d) ambient noise at frequencies of interest.

Figure 5 shows ray paths generated by the Navy Generic Sonar Propagation Model utilizing AXBT data from the study area in a water depth of 74 m. A source depth of 5 m was assumed, and for clarity only, rays generated from 0° to 10° are shown. Inspection shows surface duct propagation for the 0° and 1° rays with the −2° ray descending to approximately 55 m at a range of 2.5 km and then propagating to the surface at a range of 5 to 6 km. Bottom bounce propagation is indicated for the −3° to −10° rays.

Figure 6 shows ray paths generated for deep water in the southeast area of the *Empress II* box. This area is considerably quieter than the shallow-water area. AXBT data acquired to depth of 344 m indicated temperatures of 27.5° C at the surface and 9.9° C at the bottom. This created a strongly downward refracting medium that limited direct path reception to about 2 km and bottom bounce reception to perhaps 10 km. A shallow surface duct is evident for the 0° to −3° rays, which could, with proper conditions, increase detection significantly. We would expect more isothermal conditions as fall and winter temperatures cool the surface water, which should significantly increase detection ranges.

To determine transmission loss it was necessary to determine what frequencies were detectable in this high ambient noise environment. Filtering of recorded snapping shrimp and man-made signals revealed that reliable signals could be detected at frequencies between approximately 1 and 8 kHz in the shallow-water environment. In the deep-water environment recording of signals between 10 Hz and 10 kHz was possible. Eigenrays were calculated for frequencies of 2 and 5 kHz to determine transmission loss. Losses in shallow water at 5 km ranged between −75 and −102 dB. Similar analysis for the deep-water ray plot indicated ranges of 2 to 10 km were possible with losses at 2 and 5 kHz generally comparable to those in shallow water.

Utilizing these results we can make assumptions about the detectability of particular marine mammals. As an example we can use an ambient noise spectrum level of 55 dB//μPa in high ambient coastal waters (Urick 1983) and use previous measurements of the bottlenose dolphin (*Tursiops truncatus*), spectrum source levels, which are calculated at about 145 dB//μPa (Cummings and Fish 1971). These results indicate (at least theoretically) that these animals should be detectable at 5 km and possibly to greater ranges given reliable acoustic paths. Similar analysis for deep water assuming a spectrum ambient noise level of 50 dB//μPa (Urick 1983) and sperm whale (*Physeter catodon*) spectrum source levels of 151 dB//μPa (Levenson 1974) indicate that these animals should be detectable at ranges of 10 km or greater. With these results a circular area in which the animals should be contained can be estimated (Levenson 1978).

Given restrictions on the ability of the aircraft to carry enough sonobuoys to quantitatively establish position and numbers of odontocetes utilizing colinear arrays, it was determined that acoustically acquiring abundance and density data during this study was impractical. However, since 28 sonobuoys were randomly deployed without visual confirmation of the presence of cetaceans, it was felt that some index of odontocete occurrence could be obtained by the ratio of sonobuoy detections to nondetections.

Population Studies

Aerial surveys using a line transect method (Burnham et al. 1980) were employed to sample the study area. Five survey flights per month were conducted during November 1991 through April 1992. Survey flights were conducted during daylight hours when surface winds were, in most instances, less than 10 kt. (Occasionally, winds would build during the course of a survey, and depending on the difficulty we experienced in sighting, we would either choose to abort or to continue the mission.)

The 81.5 × 110 km study area, including the "ALT2" ship trial operating area, was divided into five equal area, north-south, rectangular blocks (see Fig. 1). Each block was divided into 44 0.5-km-wide transects. At a minimum, one transect in each block was surveyed on each survey day. Transect lines within each of the five blocks were selected at random.

All transects were surveyed from an altitude of approximately 230 m at an air speed of not more than 204 km/h (110 kt). In addition to the pilot, 2–3 observers were in the plane. The third observer was responsible for operating equipment and/or recording data. Observers searched for sea turtles and cetaceans at the surface on both sides of the aircraft.

When a sighting was made, the angle of the sighting from the transect line was measured with an inclinometer (Sunnto model PM5/360PC) and recorded. The distance that the sea turtles or cetaceans deviated from the centerline of the transect was calculated from the sighting angle and altitude. When necessary, the aircraft was diverted from the transect line to make species

identifications and to estimate marine mammal herd sizes. Attempts were made to use photographs and/or videotape recordings to confirm identification. Whenever possible, sea turtles and marine mammals were identified to species. However, in some cases, only identification to higher taxonomic levels was possible.

In addition to identifying the species (or taxonomic group) of marine animals sighted and measuring the angle these animals, or groups of animals, deviated from the transect line, the following data were recorded:

Transect data

(a) date

(b) grid and transect number

(c) starting and ending time for each transect flown

(d) cloud cover

(e) visibility

(f) glare present on each side of aircraft

(g) sea state

(h) turbidity

Observation data

(a) observer

(b) latitude and longitude

(c) flight direction (north or south)

(d) number of individuals

(e) age (adult, juvenile)

(f) direction animals were heading

Statistical Treatment of Data

Individual transect lengths were 81.5 km, so each survey day yielded $5 \times 81.5 = 407.5$ km of transect. For the entire study period, this yields $30 \times 5 \times 81.5 = 12{,}225$ km of transect. The study area was $81.5 \times 110 = 7555$ km^2.

There was a strip of 214 m (107 m on each side) beneath the aircraft that was unobservable, and observations (sightings) made at distances beyond 650 m from the centerline of the transect were not used in the analysis. The program AERTRAN provided by Quang and Lanctot (1991) was employed to estimate animal density. During each survey day an area of 442.6 km^2 was covered.

Sightings were placed into one of three categories; turtles, whales, or dolphins. For a very few observations (<5%) of delphinids, group sightings were broken down by juvenile and adult. There were insufficient data on juvenile sightings to obtain reliable estimates of age ratios. Therefore, the number of adults and the number of juveniles sighted in a group were summed to obtain one group size. In those instances where a range was given for group size, the midpoint of that range was used to estimate animal density.

Line transect sampling assumes that the probability of sighting an object from the transect line is a function of its perpendicular distance from the transect (Burnham et al. 1980). However, when species tend to form groups, there is a possibility that the number of individuals in the group influences sightability. In this case, typically larger groups have a greater chance of detectability than smaller groups. If this bias is not accounted for, then overestimation of abundance can occur (Drummer and McDonald 1987).

The bivariate sighting function of Drummer and McDonald (1987) was employed to perform a formal test for size bias. Separate analyses were performed for the turtle and cetacean data. All data for the entire study period were used in this analysis. There were never more than two turtles in a group (usually one), but group sizes ranged from 1 to over 100 for cetaceans. It was concluded that there was no size-bias in either the cetacean or sea turtle data, and respective observed mean group sizes were used as estimates of the true mean group size.

For both the turtle and cetacean data, the distance data from the entire study period were pooled to fit a detection function to each set of data. Distance distributions between observers and months were compared separately, but no clear differences could be discerned, so it was concluded that pooling was both reasonable and necessary. A detailed discussion of the statistical methods employed is included in Appendix A.

RESULTS

Acoustical Studies

Between 11 November 1991 and 10 June 1992 a total of 32 SSQ-41B sonobuoys and 10 SSQ-36 AXBTs were deployed in the *Empress II* area. Marine mammal sounds were recorded on 12 sonobuoys (38%). These sounds were recorded both in the vicinity of visually identified cetaceans (4 sonobuoys) and when no animals were visually apparent (8 sonobuoys). Initial analysis of sounds recorded in the vicinity of visually identified animals and recorded sounds when no animals were observed was conducted aurally by comparing sounds of identified animals recorded by various investigators (e.g., Tavolga 1968) and comparing these to sounds recorded from the aircraft. When a qualitative match was found, identified sounds were digitized and compared to those recorded from the aircraft. Figure 7 shows a 480 ms series of known sperm whale clicks. Figure 8 shows a 300 ms series of clicks recorded in relatively deep water in the southeast corner of the *Empress II* study area. These clicks have the "hammering-carpenter" sounds distinctive in sperm whale vocalizations. Power spectrum analysis of relative amplitude vs. frequency of a click in these two sounds is shown in Fig. 9. Sonograms of time vs. frequency and relative amplitude are shown in Fig. 10 for the known sperm whale sound and Fig. 11 for the *Empress II* sound. These also show similar frequency and amplitude characteristics. Individual clicks in this presentation can be compared. For example, taking into account time compression and amplitude differences between these signals, the third click in Fig. 10 can be compared to the last click in Fig. 11. To further analyze these sounds, spectrograms of 512 point cuts of the known sound (Fig. 12) and the *Empress II* sound (Fig. 13) were compared. These spectrograms take sounds shown in Figs. 7 and 8 and serially

display results in a waterfall presentation. Inspection shows that frequency and power envelopes are similar in both analyses. Comparing points 1536, 5120, and 5632 in Fig. 12 with points 1536, 3072, and 3584 in Fig. 13, respectively, shows similar waveform and amplitude characteristics. Similar analyses were done with all identifiable sounds recorded in the *Empress II* area.

It appears fairly certain from visual and acoustic data that the overwhelming preponderance of marine mammals in the *Empress II* area consisted of bottlenose dolphins. Figure 14 shows a spectrogram of a whistle recorded from the aircraft in the vicinity of visually identified bottlenose dolphins in the *Empress II* area. Figure 15 shows a sonogram of 2 whistles and Fig. 16 shows a sonogram of clicks recorded in the vicinity of these same dolphins.

Figures 17 through 21 show sonograms of acoustically identified cetaceans in the *Empress II* study area. Figure 17 shows the sonogram of a pilot whale (*Gobicephela* spp.), Fig. 18 of spotted dolphins (*Stenella* spp.) Fig. 19 of saddleback (= common dolphins (*Delphinus delphis*), Figs. 20 and 21 of unknown odontocete squeals and clicks, respectively. Figure 22 shows a sonogram of what is believed to be snapping shrimp. Baleen whales (*mysticetes*), were neither recorded nor observed in the area.

Population Studies

There were 83 sea turtle sightings, 103 dolphin sightings, and 13 whale sightings during the entire study period. The number of sightings of each species or taxonomic group was summarized by month from November 1991 to April 1992. Plots were made showing the distribution of sea turtles and marine mammals in the study area (Figs. 23–28).

Figures 23–28 show the number and the location of sea turtles and cetaceans sighted in the study area each month. In general, we had more difficulty identifying marine mammals than the large sea turtles during this survey. This was due, in part, to the fact that most sea turtles appeared to be floating at the surface, which allowed us to circle them sufficiently to confirm identification. It was difficult to positively identify the smaller turtles from the air.

Aside from the bottlenose dolphins, we had little success in identifying species of other dolphin and whales from the aircraft. A combination of factors outside our control (e.g., animals diving or swimming beneath the surface, sea glare, etc.) contributed to our inability to see characteristics essential for identification. Also, some cetaceans, especially the larger species, appeared to spend little time at the surface. It is possible that the sound of the approaching aircraft startled these individuals and caused them to dive. The sound of our aircraft was audible from deployed sonobuoys. We believe that the large herds (75 to over 150 individuals) of very active dolphins that were generally sighted in the deeper water in the southern part of the study area were probably Atlantic spotted dolphins (*Stenella frontalis*) or pantropical spotted dolphins (*S. attentuata*). These herding species were reported as *Stenella* spp. and other unidentified species were reported simply as unknown whales or dolphins. None of the photographs or videotape recordings made during any of the flights were of sufficient quality to be used for identification.

Abundance estimates for sea turtles and cetaceans were also computed for each month (Tables 1 and 2). The monthly estimates can be thought of as estimates of the average abundance of the 5 days flown each month. For both cetaceans and turtles, the distance data were pooled from all survey days to obtain estimates of sightability. Variability in the estimates from month to month can be attributed to variation in number of sightings and variation in mean group size. Due to limited data, it was not possible to compute standard errors (SE) for the monthly abundance estimates.

Table 1 — Estimated Monthly Sea Turtle Abundance. The Estimates Represent an Estimate of the Average Abundance for the 5 Days Flown During that Month.

Month/Year	Number of Sightings	Mean Group Size	Abundance Estimate
Nov/91	8	1.00	33
Dec/91	17	1.00	70
Jan/92	23	1.04	98
Feb/92	5	1.00	21
Mar/92	2	1.00	8
Apr/92	28	1.00	115

Table 2 — Estimated Monthly Cetacean Abundance. The Estimates Represent an Estimate of the Average Abundance for the 5 Days Flown During that Month.

Month/Year	Number of Sightings	Mean Group Size	Abundance Estimate
Nov/91	16	8.63	566
Dec/91	17	14.18	988
Jan/92	26	14.27	1520
Feb/92	22	11.73	1057
Mar/92	12	7.83	385
Apr/92	23	3.13	295

The estimated average abundance of sea turtles in the *Empress II* area during the study period was 57.34 ± SE 15.31. The estimated average abundance for all whales and dolphins in the study area during the same period was 802.80 ± SE 208.56. The cetacean abundance estimates were based on an average group size of 10.12. These represent the estimated average abundance for the 30 survey days over a 6-month study period.

DISCUSSION

Numbers of sea turtles and cetaceans found in the study area were less than those that have been reported for other areas in the northern Gulf of Mexico. Lohoefener et al. (1990) reported a fall sighting rate (individuals observed/100 km flown) for sea turtles of 1.80/100 km and a winter sighting rate of 0.83/100 km in waters east of the Chandeleur Islands off the coast of Louisiana. We found a density of 0.01 sea turtles/km^2 in the *Empress II* study area. This translates into a sighting rate of approximately 0.68 turtles/100 km. Considering that sea turtles are ectothermic (cold blooded) and the survey was conducted, for the most part, during the coldest time of the year, we had not expected to encounter many turtles. In our study, the greatest number of sea turtles were found during the months of December, January, and April. (We collected preliminary data that showed the sea turtles were generally associated with warmer water, but we were unable to obtain

sufficient temperature measurements to confirm this observation.) Except for the leatherbacks, few of the sea turtles we sighted were actively swimming, in fact, most appeared to be basking at the surface, which facilitated identification.

Mullin (1988) found bottlenose dolphin densities in the same area east of the Chandeleur Islands to range from 0.35/km^2 to 0.58/km^2 with a peak during the winter. Mullin et al. (1991) reported overall densities of cetaceans on the upper continental shelf of 0.78 cetaceans/km^2. Cetacean density in this study was 0.11/km^2 with monthly estimates ranging from 0.04/km^2 to 0.20/km^2. The difference between our population estimates and those of previous studies may be attributed to natural variability.

The acoustic thrust of this study was to record sounds of visually identified cetaceans, determine if cetaceans were in the area when they could not be observed, identify genus and possibly species of acoustically recorded cetacean emissions, and estimate abundance and density. Given the restrictions on the ability of the aircraft to carry enough sonobuoys to establish positions and numbers of odontocetes utilizing colinear arrays, it was determined that acoustically acquiring abundance and density data during this study was impractical. This was true for the shallow-water environment found in most of the study area, but in the deep water just south of the study area we subjectively estimate between 3 and 8 sperm whales were recorded from a single sonobuoy. Acoustic methods currently used do, however, enable detection and probable identification of toothed whales within a nominal 5 to 15 km radius of deployed sonobuoys and indicate their occurrence without visual observations.

The presence of pilot whales (probably *Gobicephela macrorhynchus*), spotted dolphins (*Stenella* spp.), and saddleback dolphins in the *Empress II* study area was indicated by acoustical methods. Saddleback dolphins have been reported in the Gulf of Mexico, but their occurrence has not been confirmed (Schmidly 1981; Mullin et al. 1991; Mullin, pers. comm.). Sperm whale vocalizations were recorded in the deep water south of the study area. In addition, recordings of squeals and clicks from unknown odontocetes were made. Of these, only *Stenella* spp. was identified visually. We believe that this technique has promise as a means for identification of the toothed whales.

These results indicate that odontocetes can probably be detected and identified to 5 km or more in the shallow-water portion of the *Empress II* area by filtering signals recorded below 1 kHz and signals somewhere between 4 and 5 kHz to eliminate snapping shrimp noise. In the deep-water portion of the area, we can probably detect these animals at significantly greater ranges given sound velocity profiles more conducive to propagation. Acoustical techniques appear to be superior to photography for cetacean (odontocete) identification.

The line transect aerial survey appeared adequate for monitoring population trends in the study area. Of course, as in other marine mammal surveys, these abundance estimates neglect submerged cetaceans. A general approximation of the number of cetaceans missed during the course of this study can be obtained from the acoustical data. Of the sonobuoys that were randomly deployed in areas where no cetaceans were sighted, 29% (8 of 28) detected cetaceans. Assuming this percentage represents the probability of missing submerged cetaceans, we believe that it is appropriate, as a first approximation, to assign a correction factor of 1.3 to the population estimates made from visual observations. Using this factor, the density of cetaceans in the study area would be 0.14/km^2 (monthly range: 0.05/km^2–0.26/km^2). We believe that these adjusted estimates better approximate cetacean abundance in the *Empress II* ship trial area.

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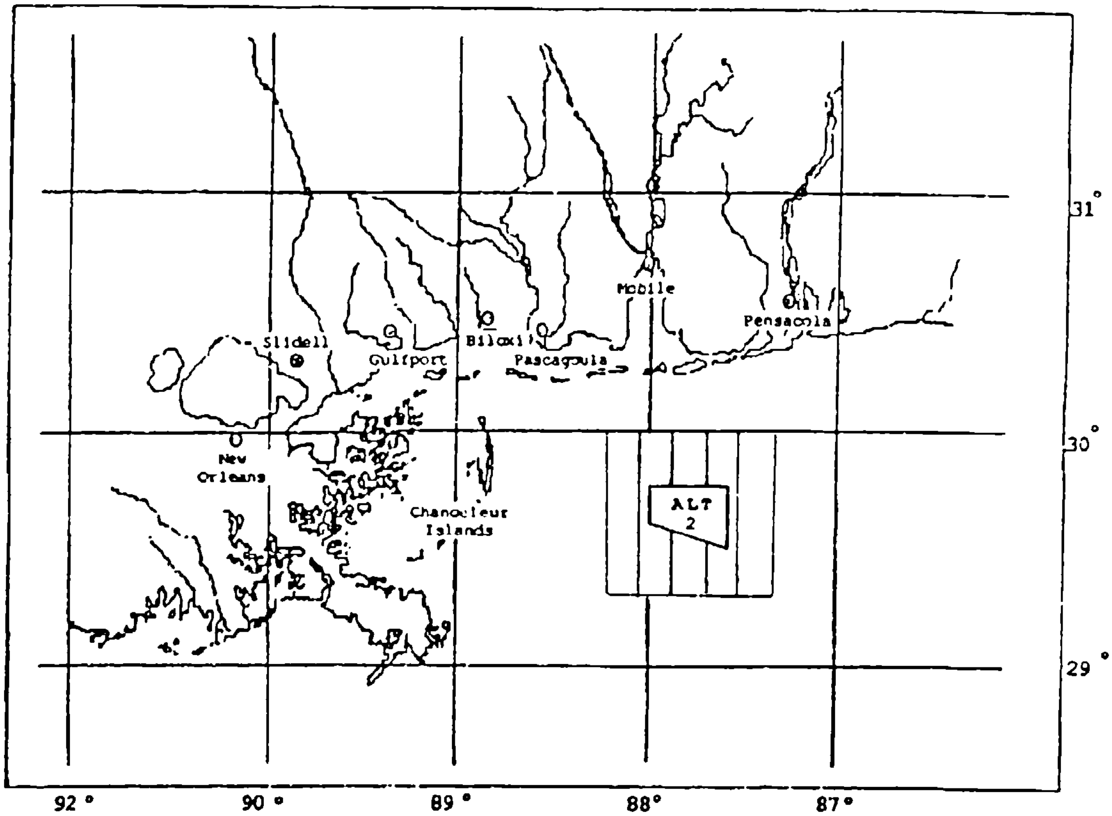


Fig. 1 — Map of north-central Gulf of Mexico showing approximate location of study area (*Empress II* ship trial operating area, Alt. 2)

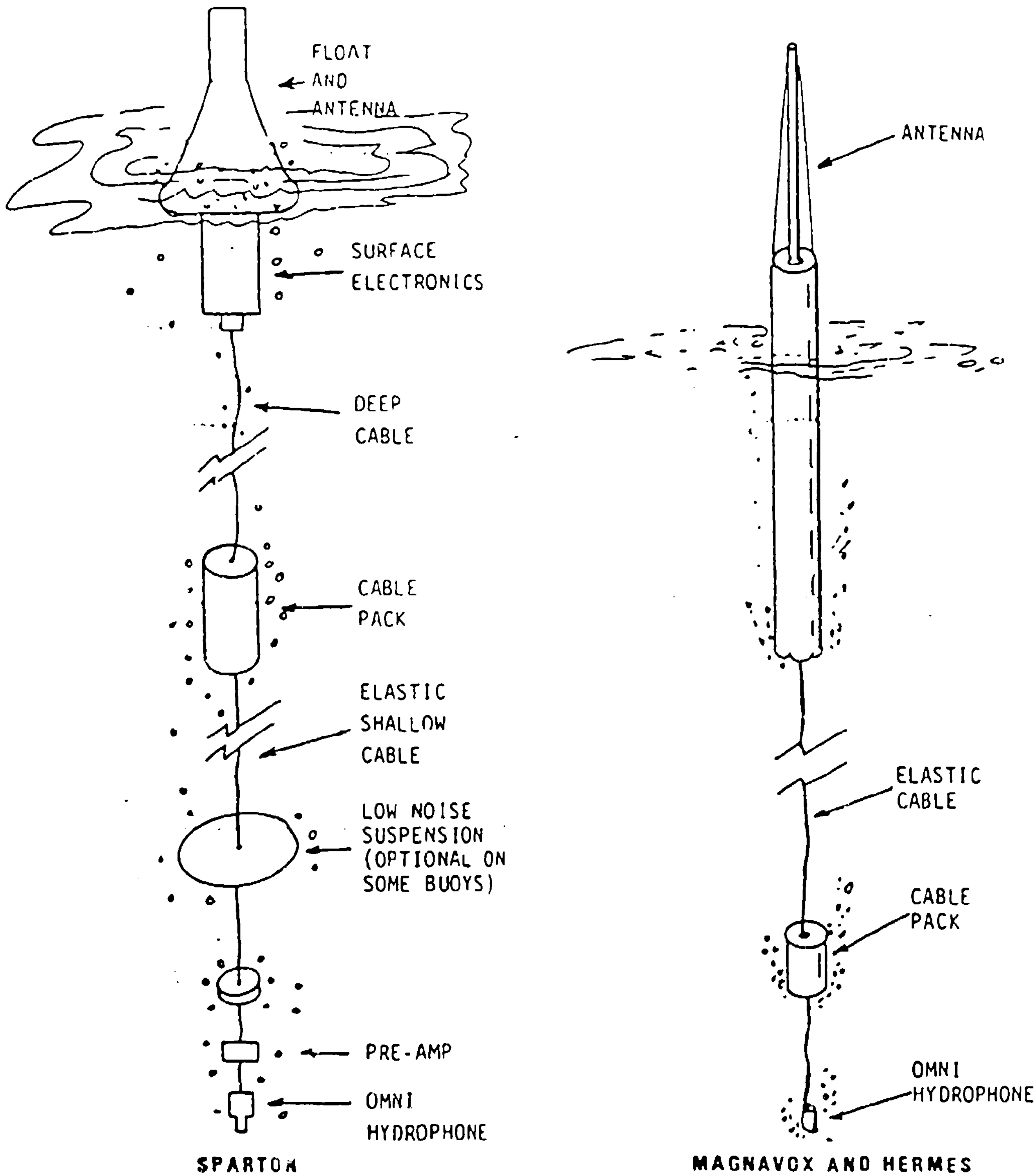


Fig. 2 — AN/SSQ-41B sonobuoy deployment

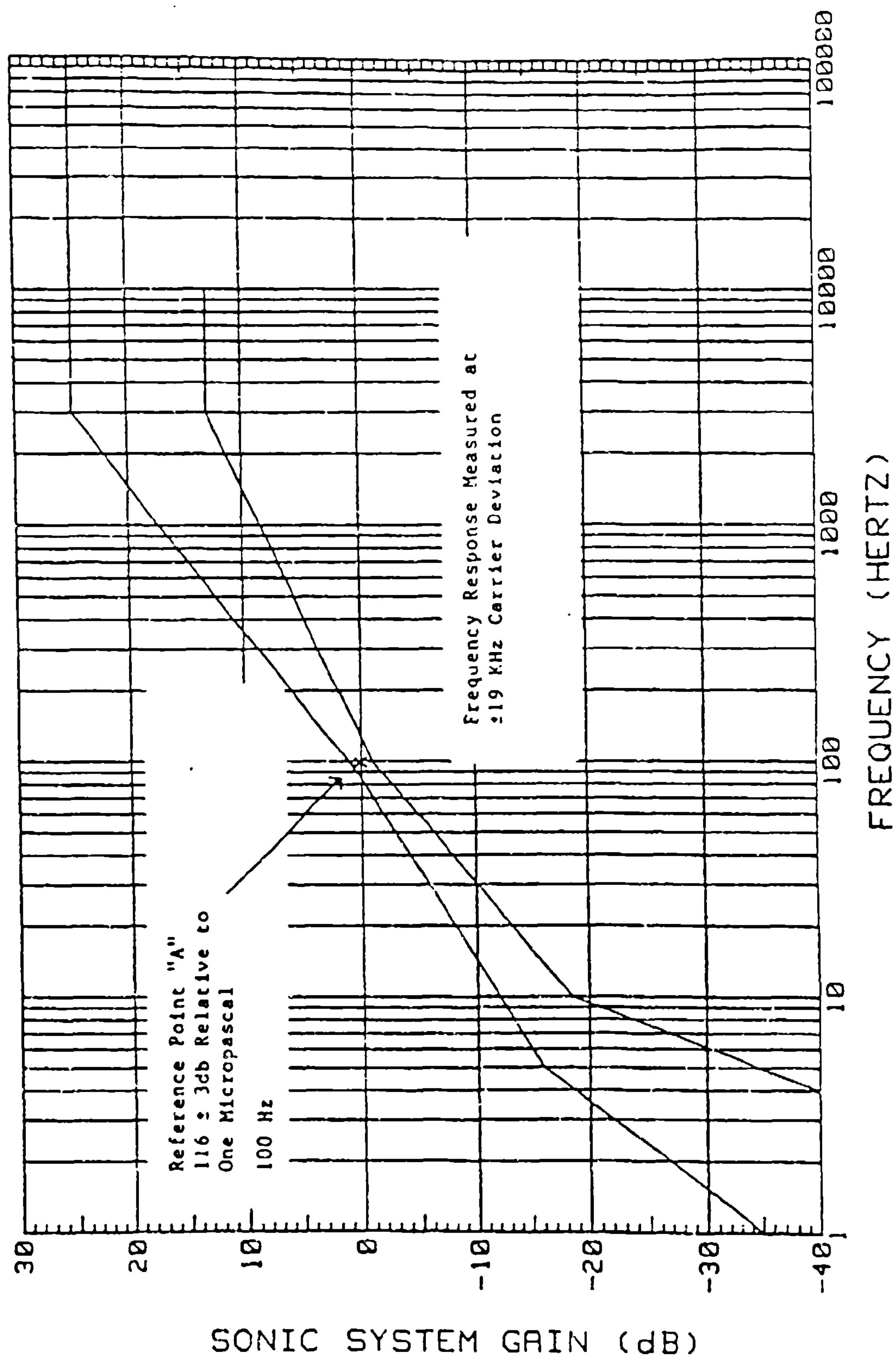


Fig. 3 — Frequency response envelope for AN/SSQ-41B sonobuoy

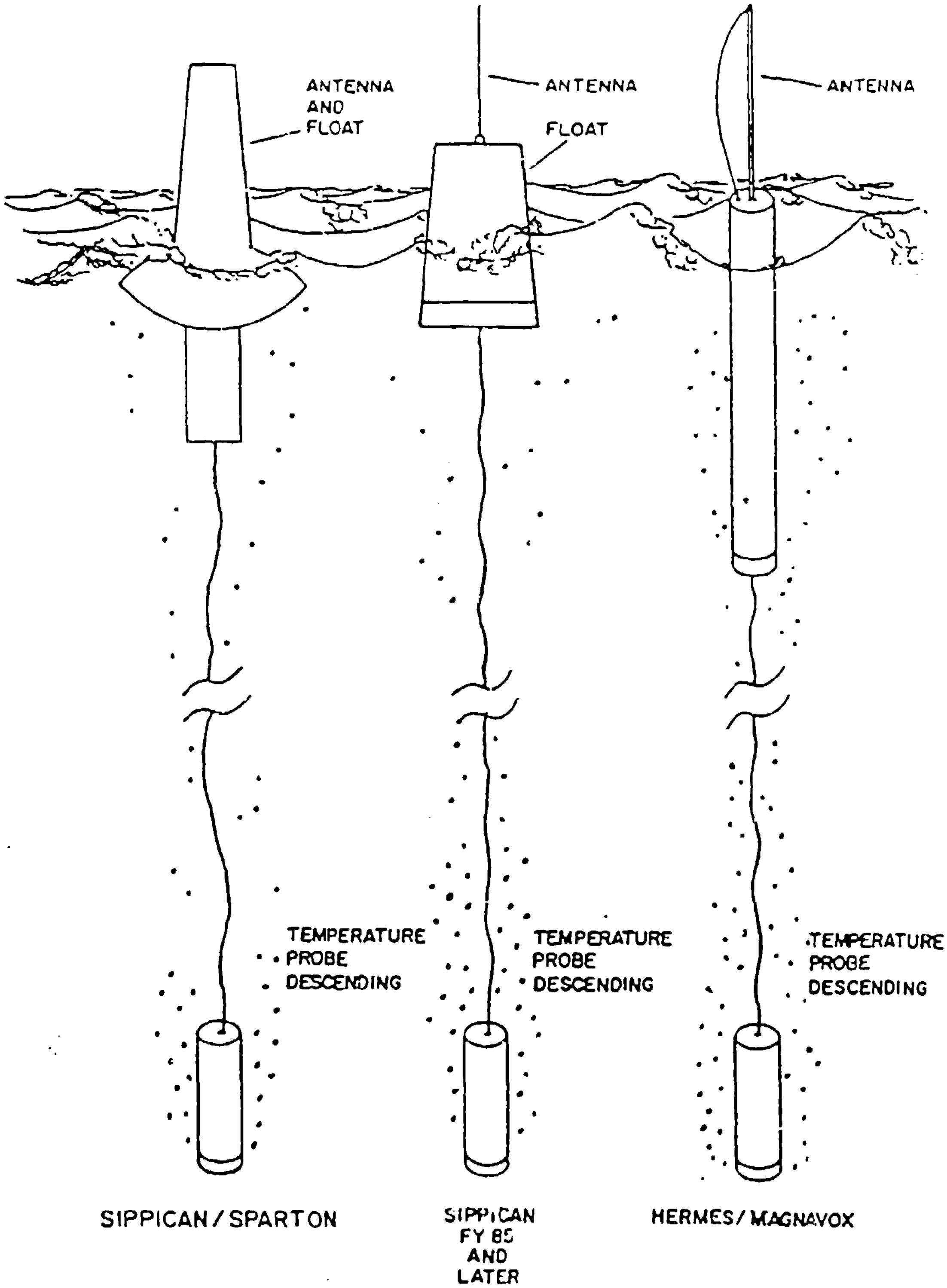


Fig. 4 -- AN/SSQ-36 AXBT sonobuoy deployment

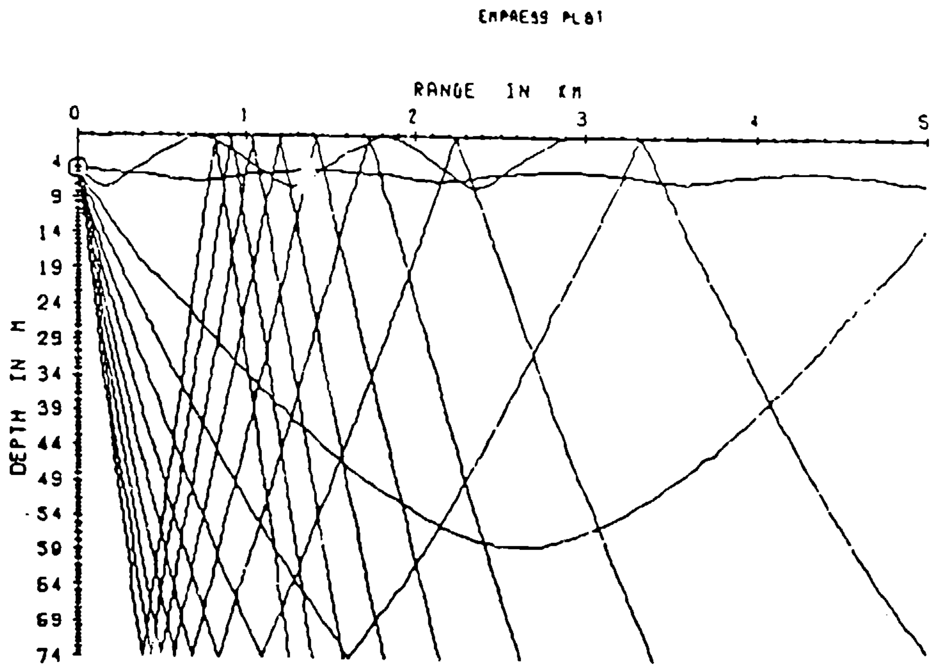


Fig. 5 — Ray plot for shallow water in the *Empress II* area

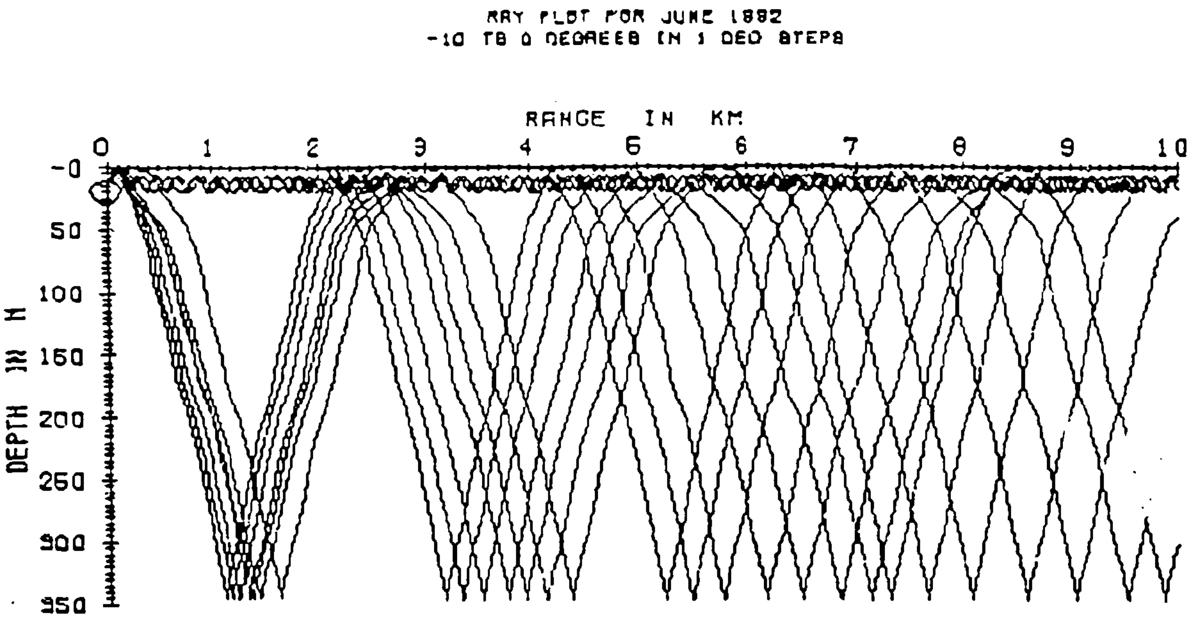


Fig. 6 — Ray plot for deep water in the *Empress II* area

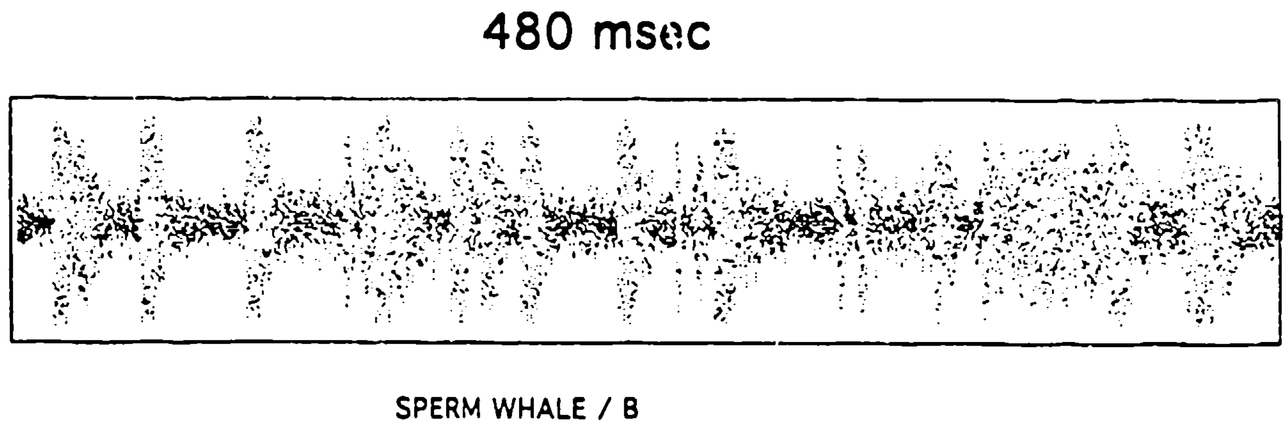
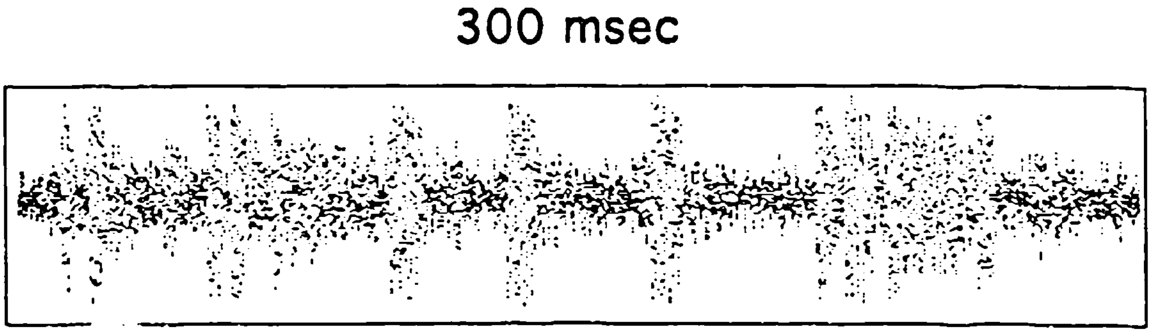
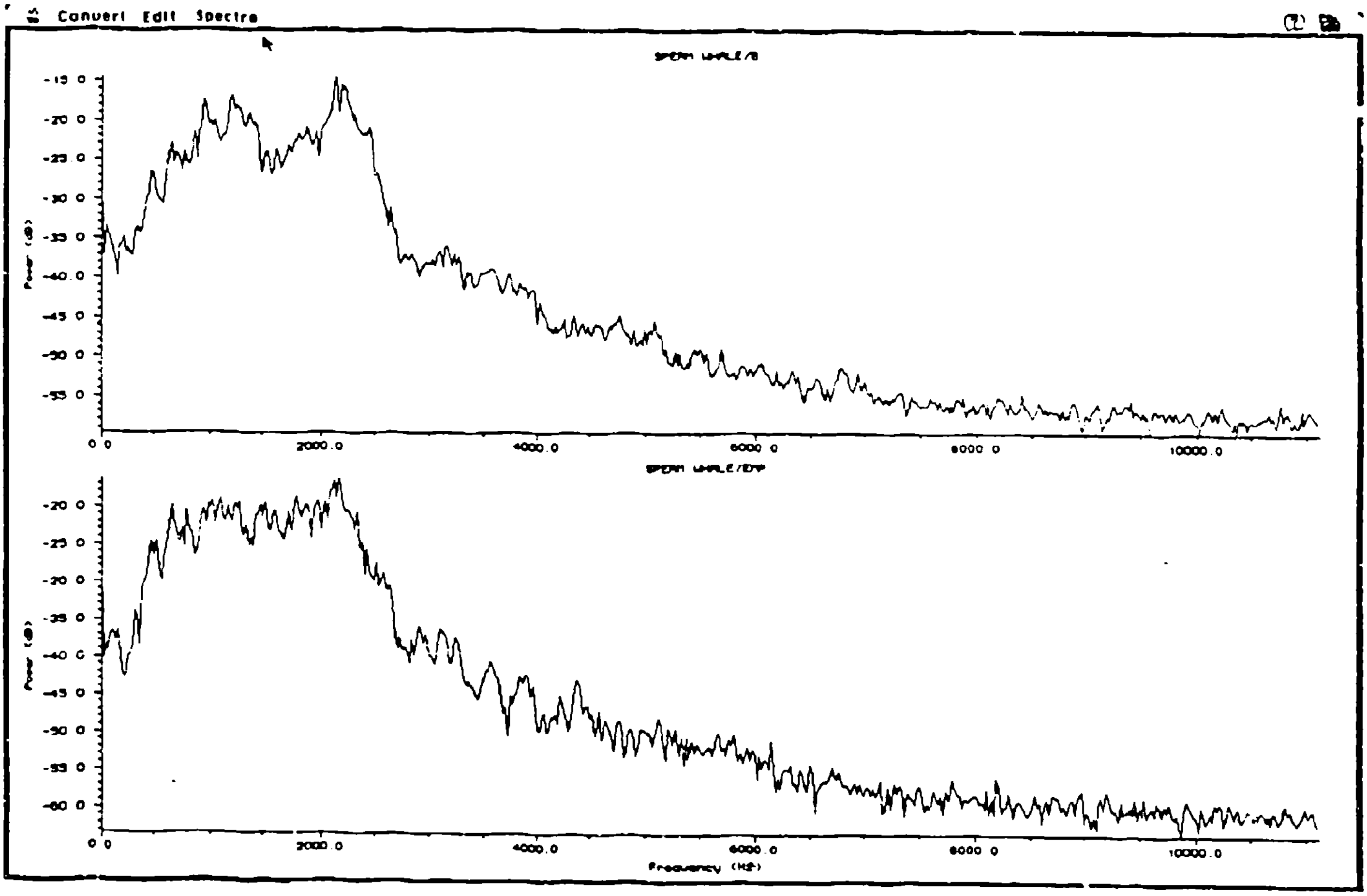


Fig. 7 — Sperm whale clicks recorded in the North Atlantic ocean



SPERM WHALE/EMP

Fig. 8 — Sound recorded in the *Empress II* area on SSQ-41B sonobuoy



POWER SPECTRUM

Fig. 9 — Power spectrum comparison of Figs. 7-8

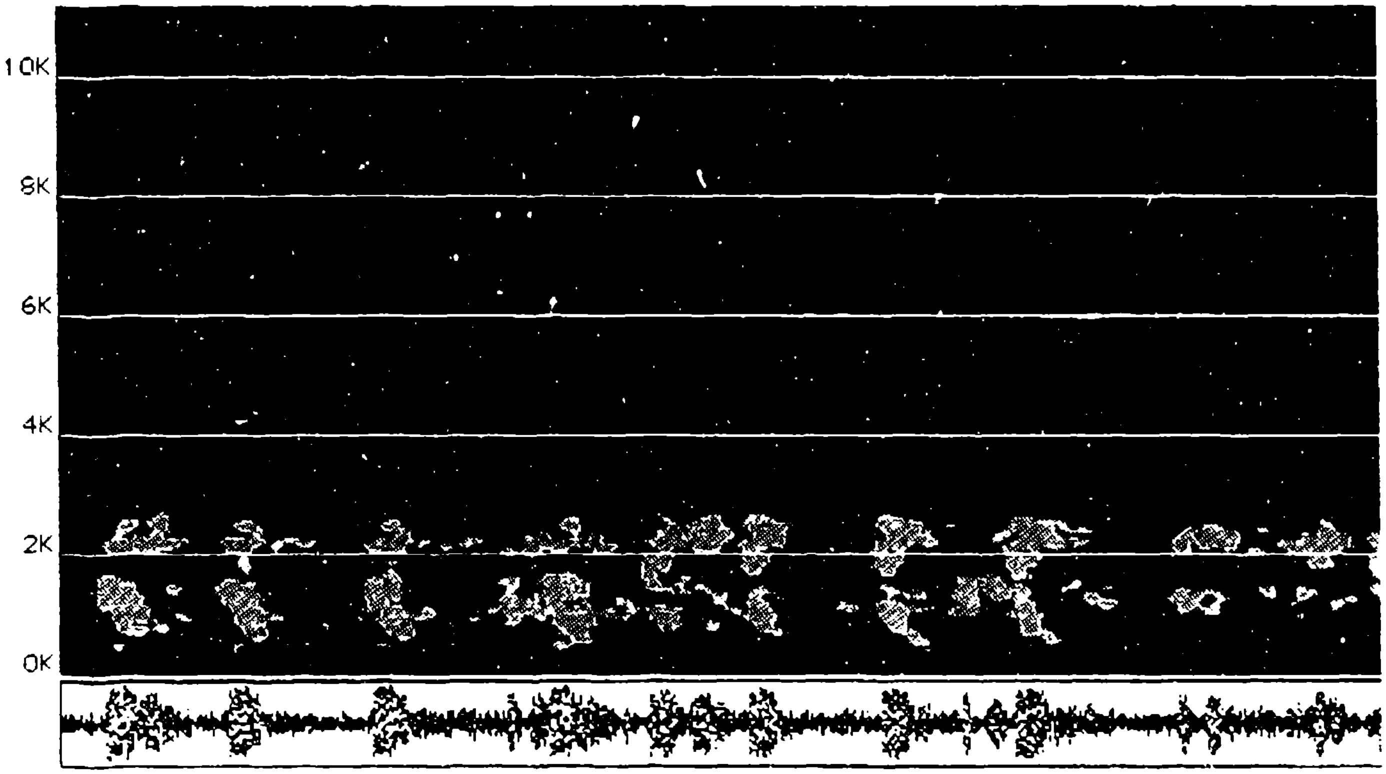


Fig. 10 — Sonogram of sperm whale recorded in the North Atlantic ocean

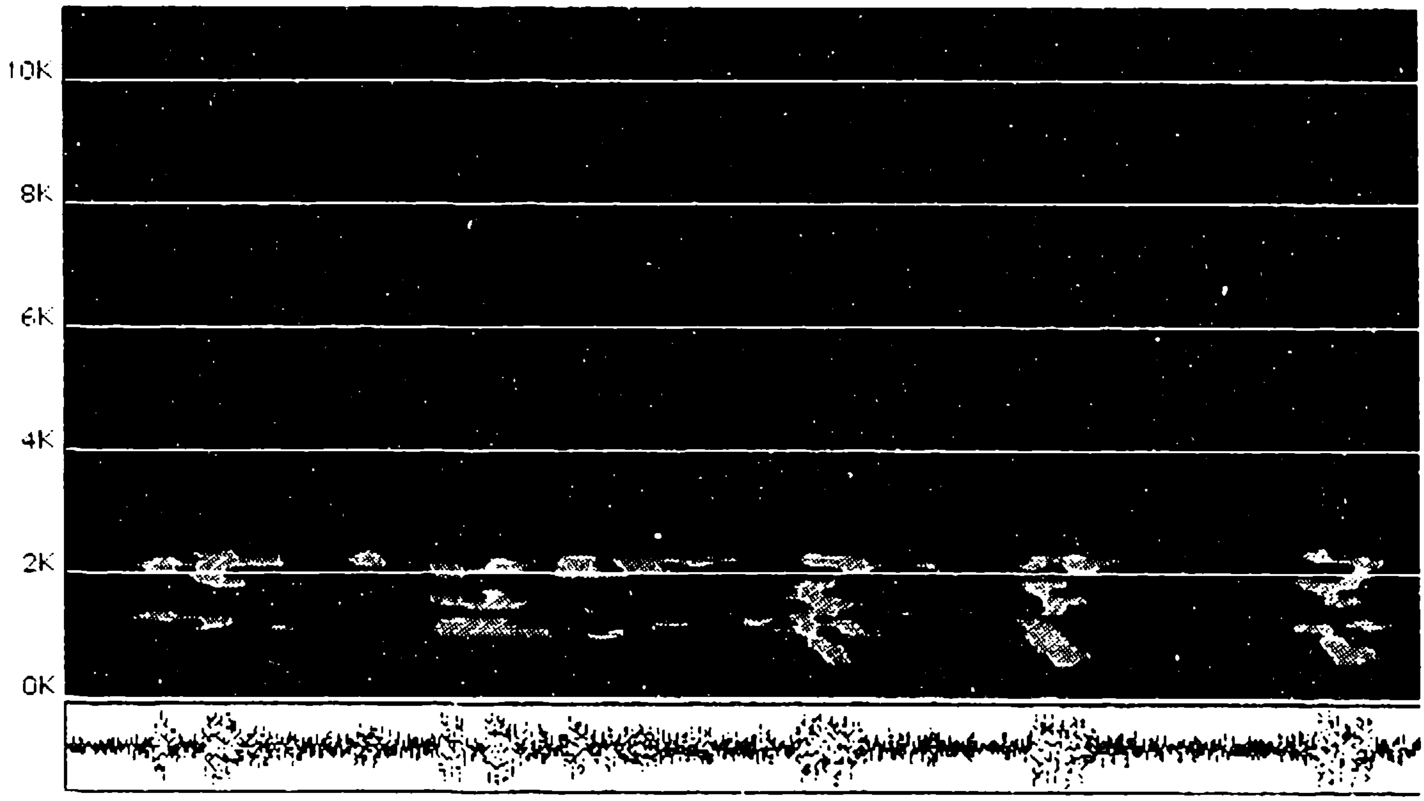


Fig. 11 — Sonogram of sound recorded in the *Empress II* area

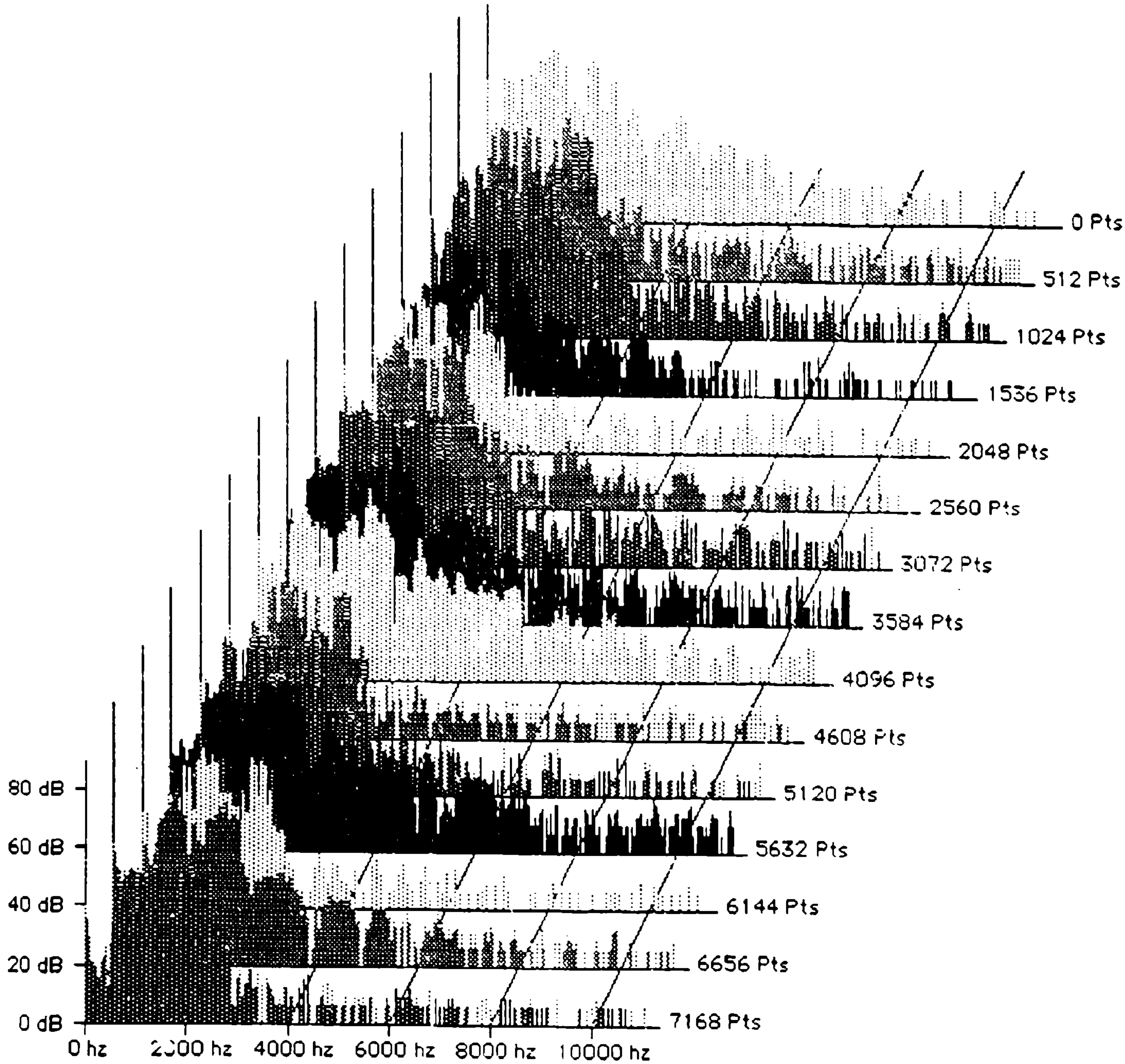


Fig. 12 — Spectrogram of sperm whales recorded in the North Atlantic ocean

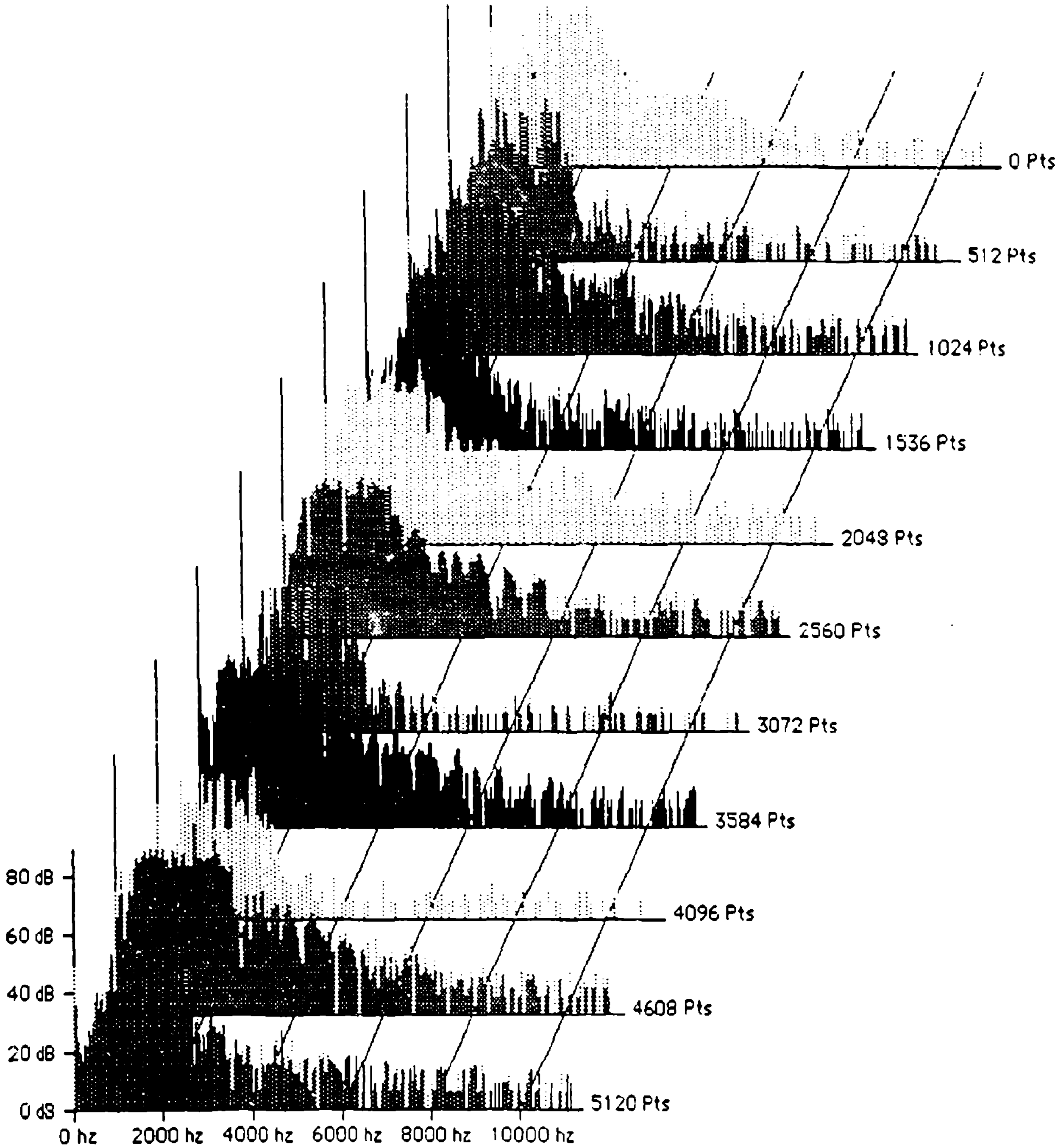


Fig. 13 -- Spectrogram of sound recorded in the *Empress II* area

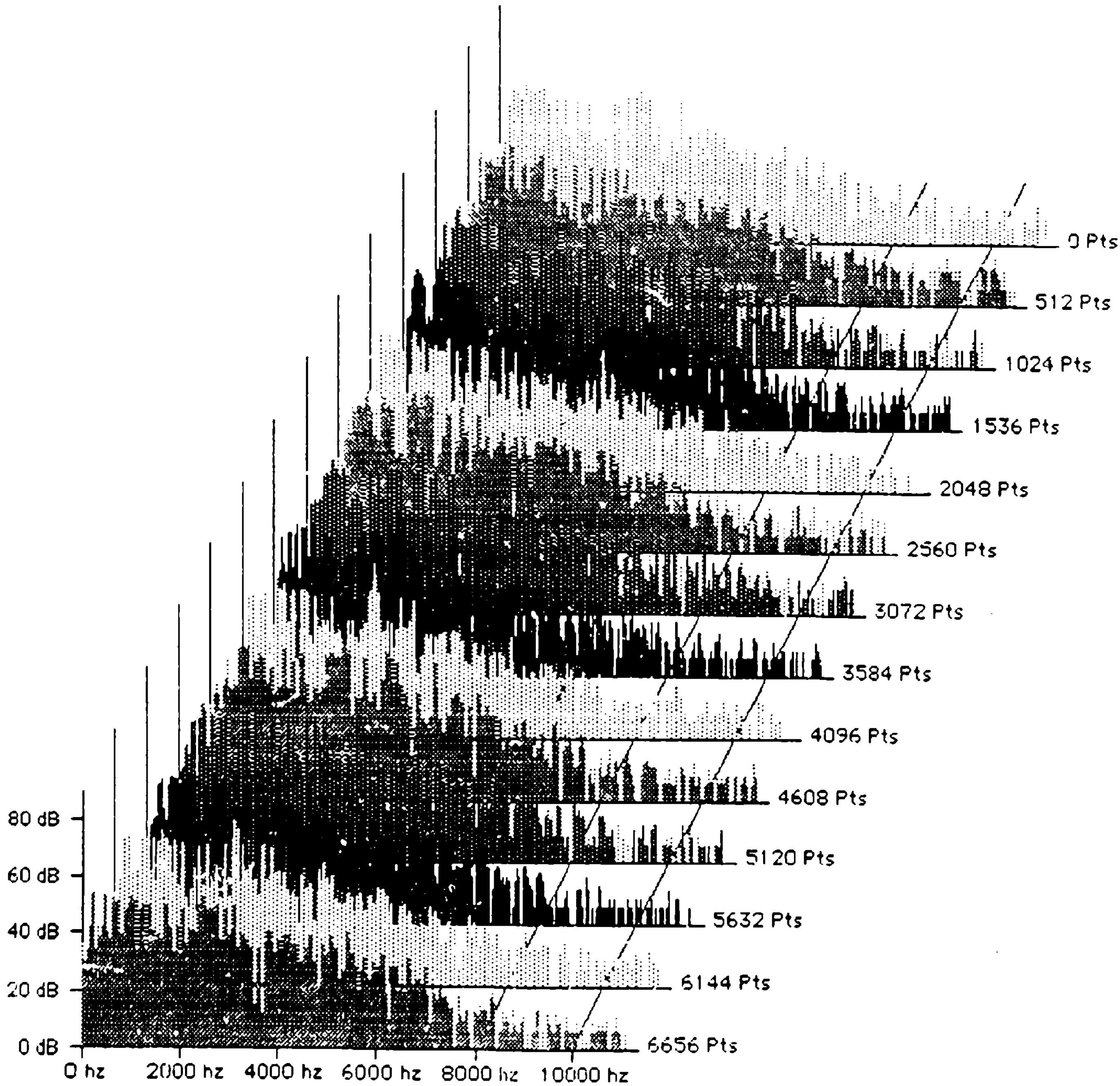


Fig. 14 — Whistle recorded in the vicinity of bottlenose dolphins in the *Empress II* area

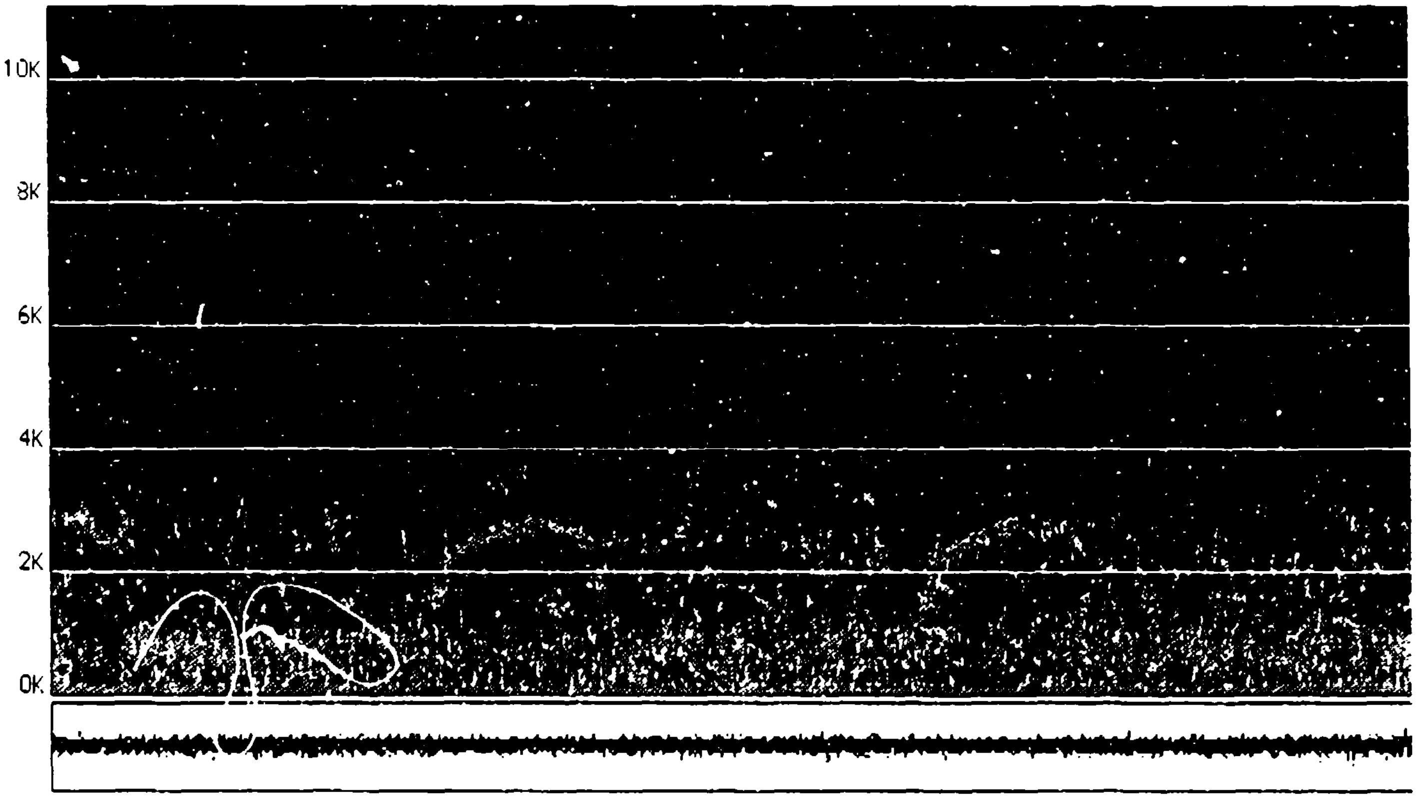


Fig. 15 — Sonogram of 2 whistles recorded in the vicinity of 14 bottlenose dolphins in the *Empress II* area

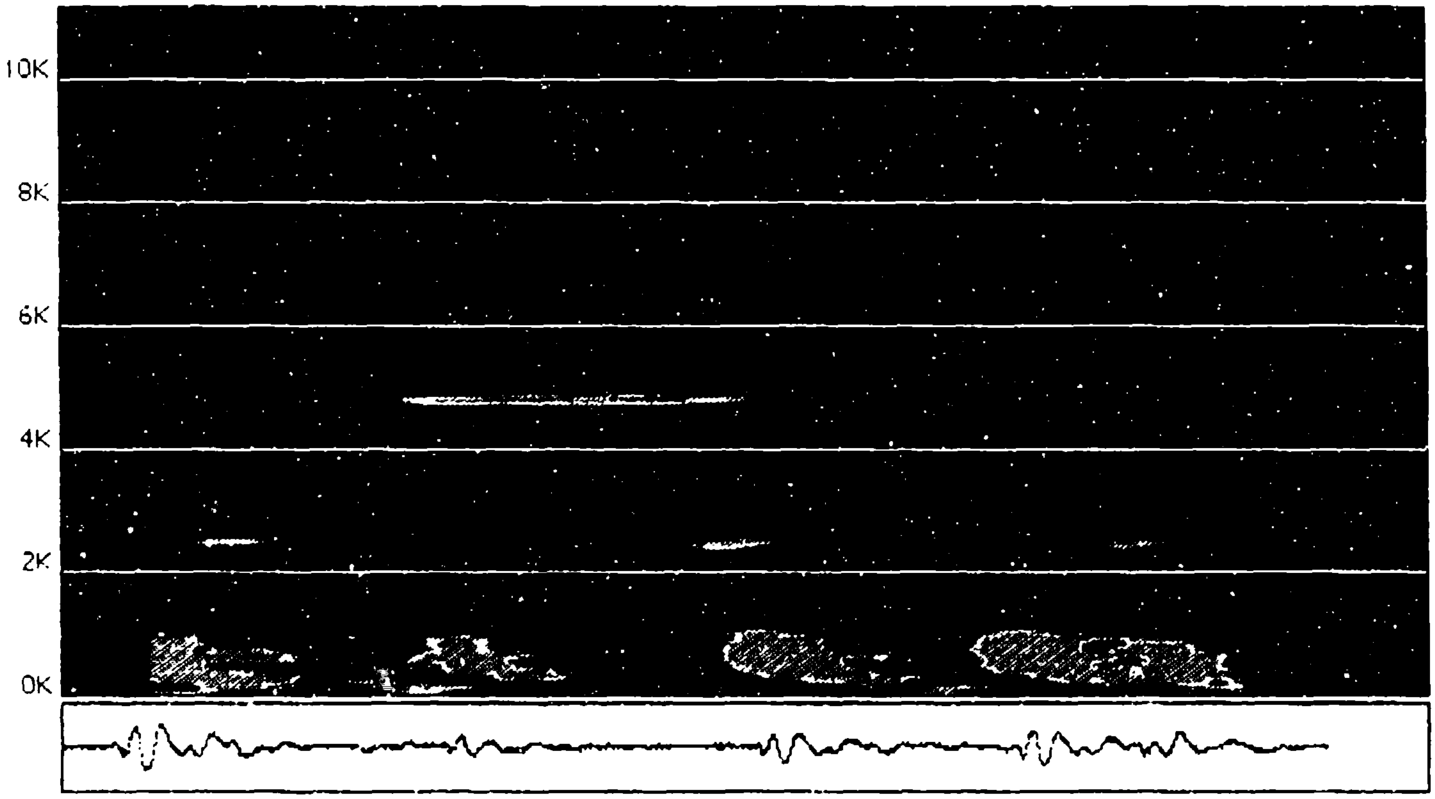


Fig. 16 — Sonogram of clicks recorded in the vicinity of bottlenose dolphins in the *Empress II* area

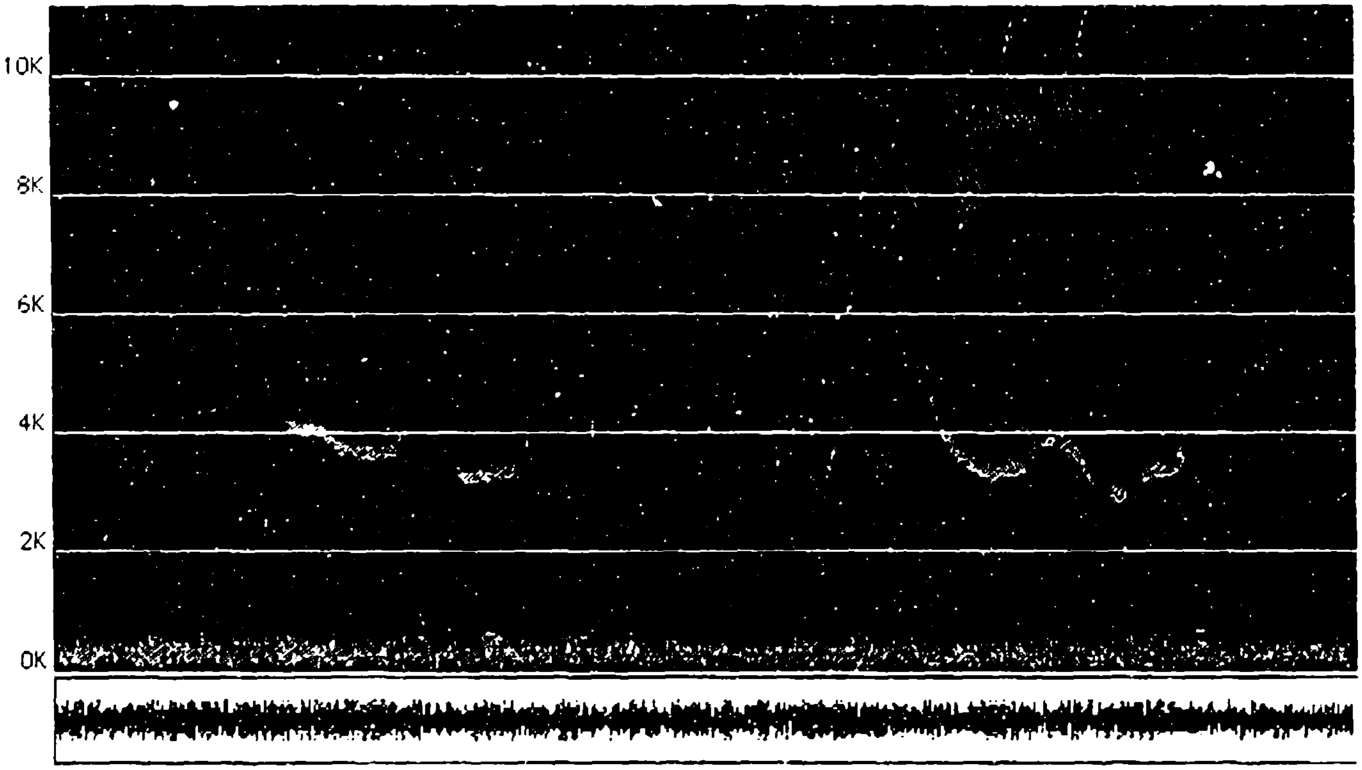


Fig. 17 — Sonogram of whistles recorded in the vicinity of pilot whales in the *Empress II* area

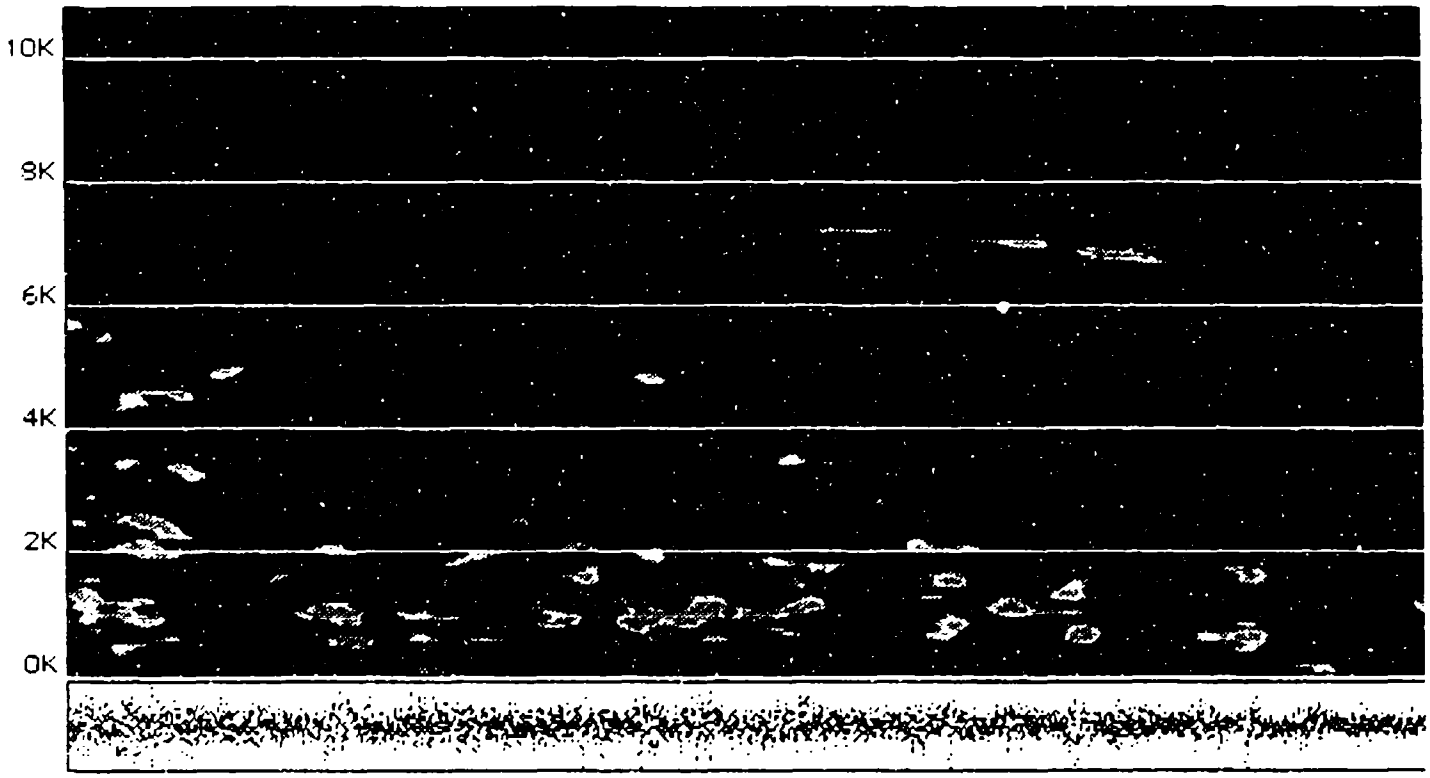


Fig. 18 — Sound recorded in the vicinity of spotted dolphins in the *Empress II* area

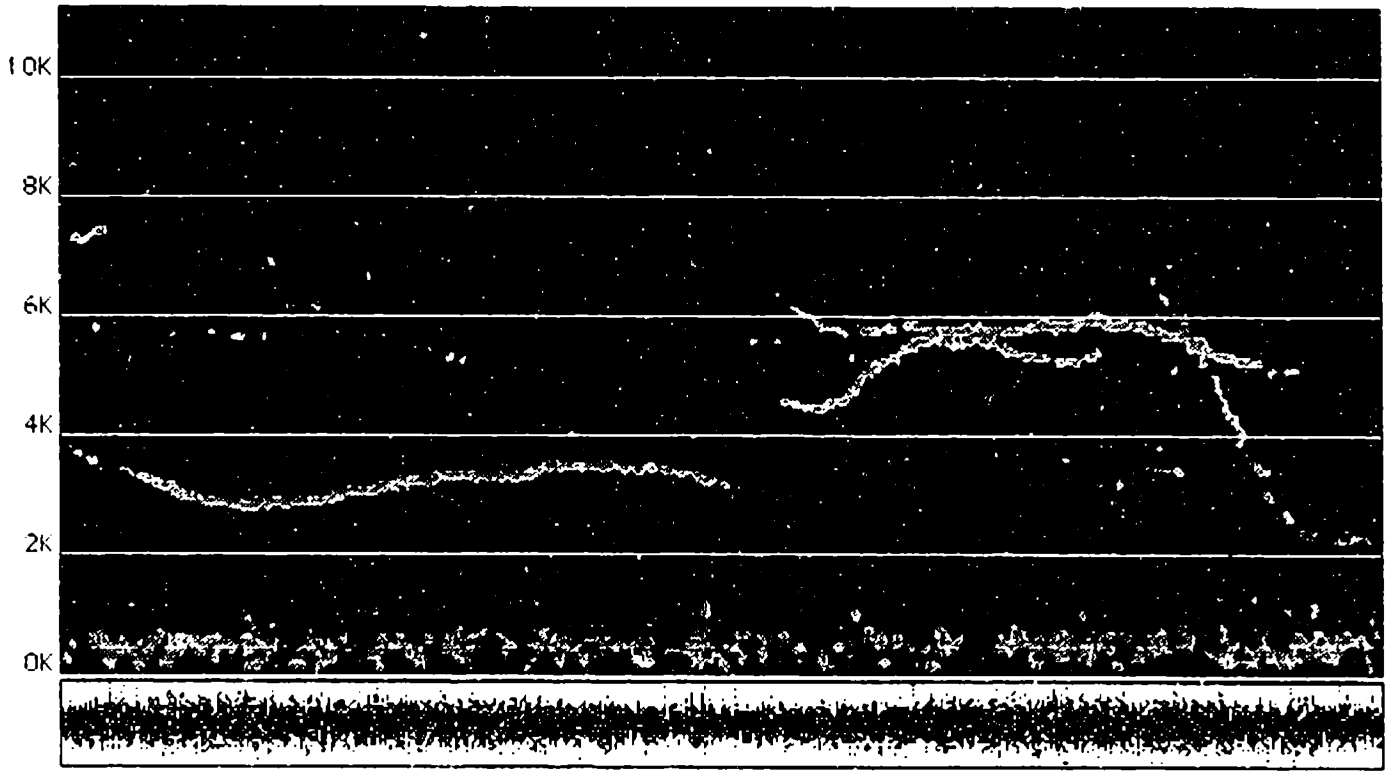


Fig. 19 — Whistles recorded in the vicinity of saddleback dolphins in the *Empress II* area

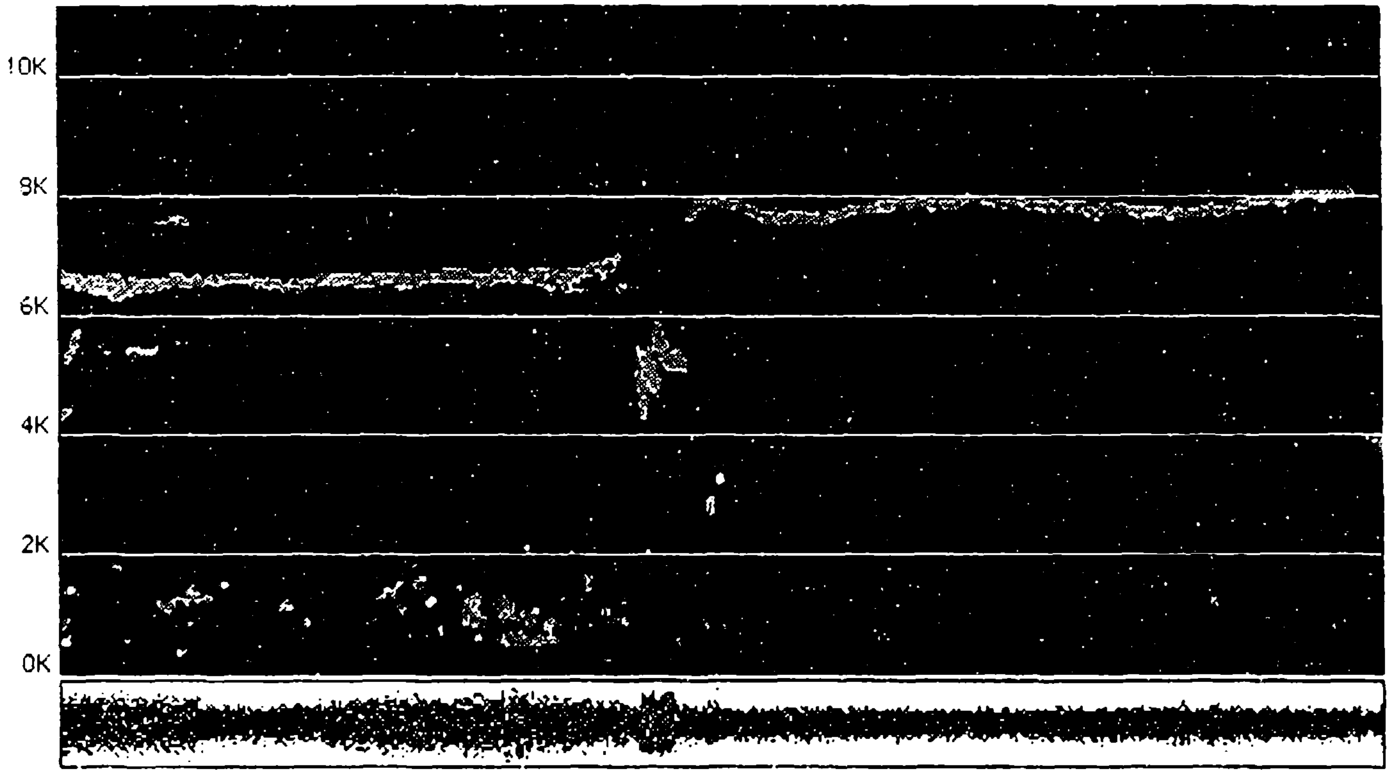


Fig 20 · Unknown odontocete squeals in the *Empress II* area

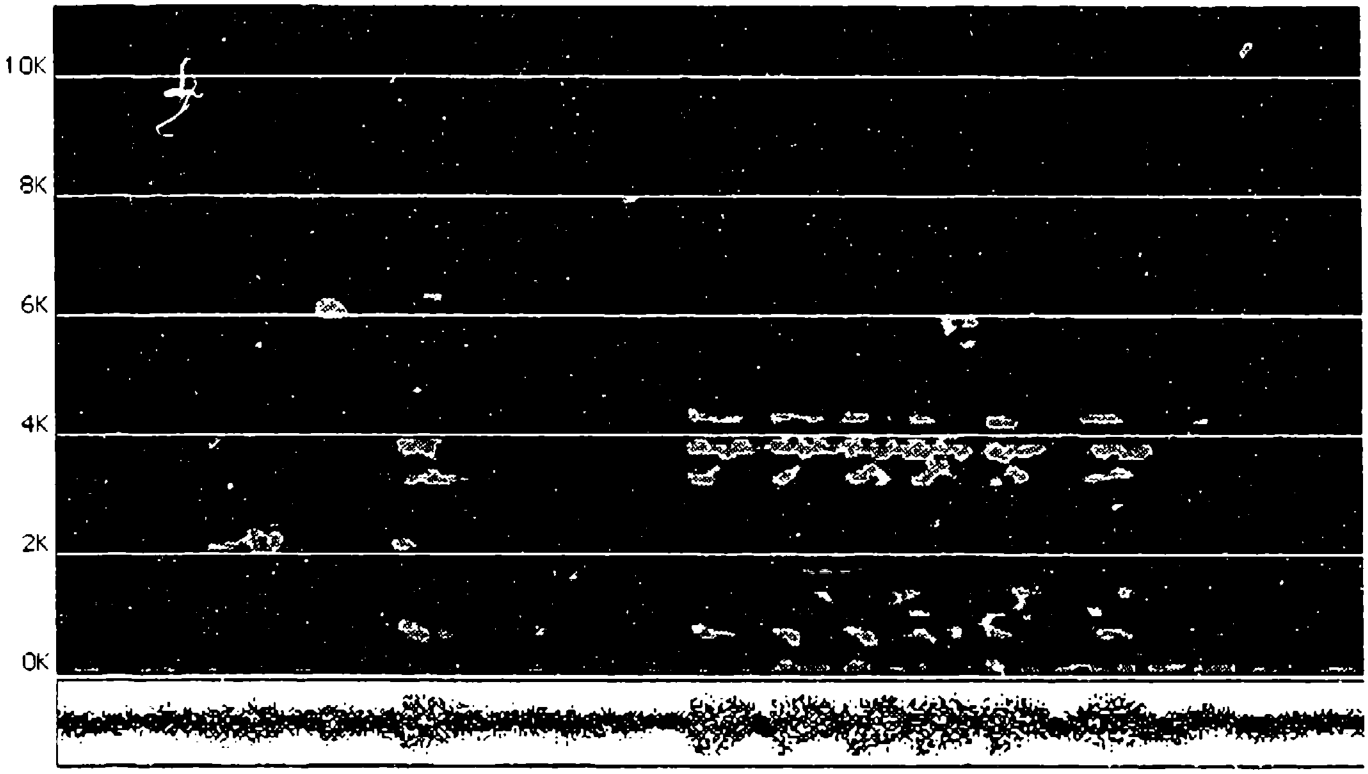


Fig. 21 -- Unknown odontocete clicks in the *Empress II* area

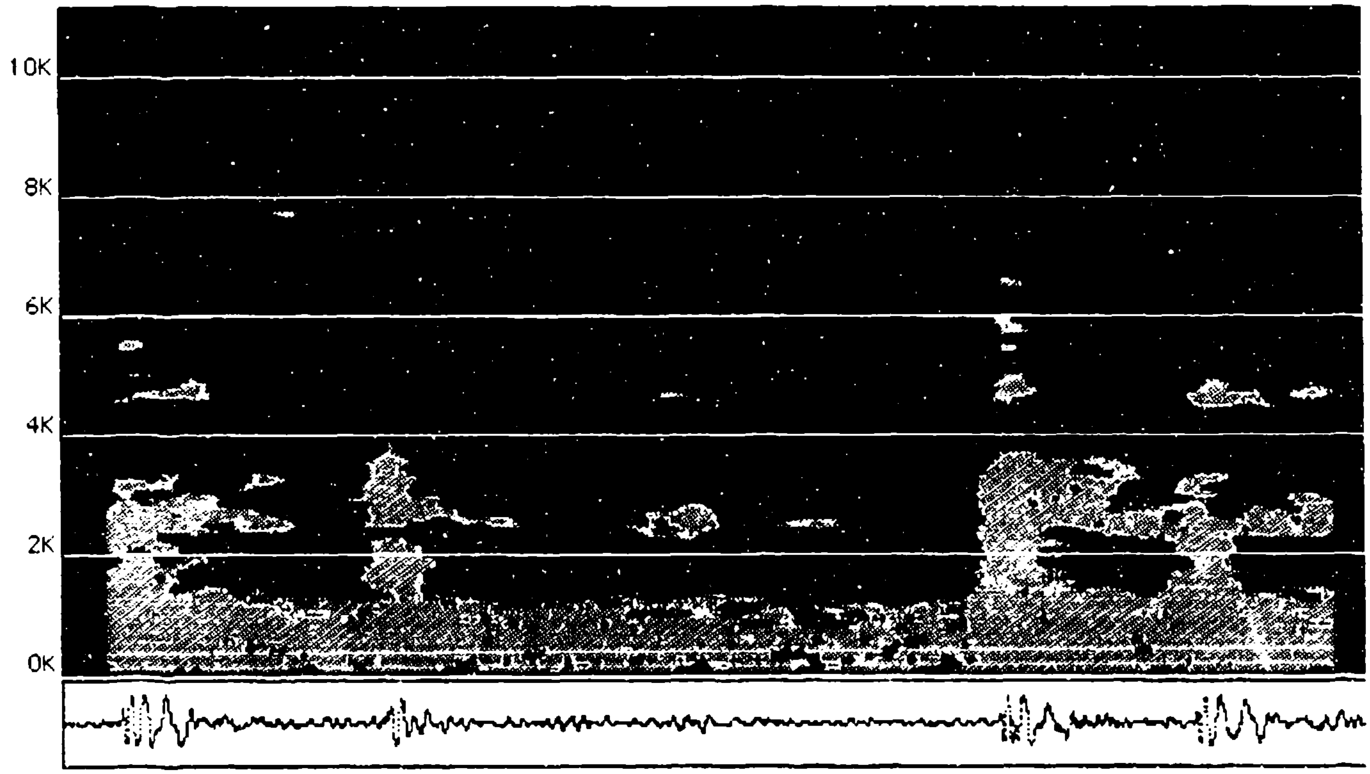


Fig. 22 — Sonogram of snapping shrimp in the *Empress II* area

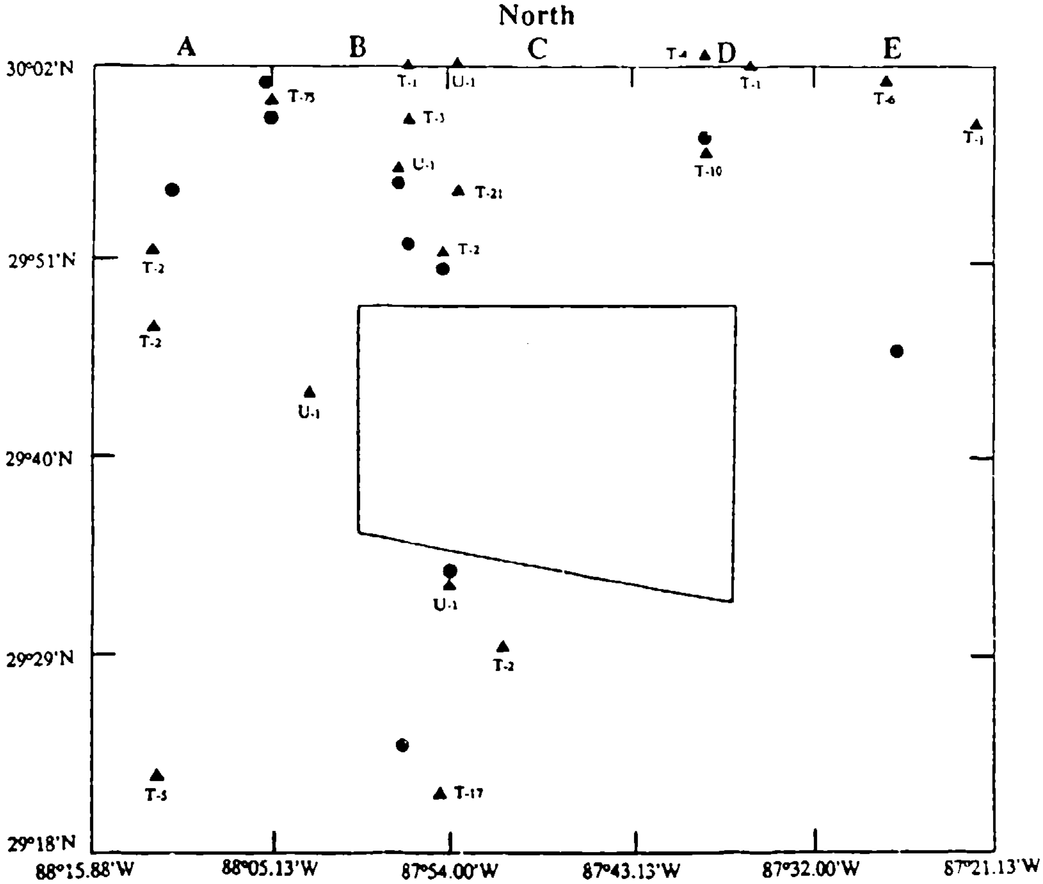


Fig. 23 -- Location of all sea turtles (circles) and cetaceans (triangles) observed in the *Empress II* study area and operating area during November 1991. A circle indicates the sighting of one sea turtle. The number of whales counted or estimated at each location is shown next to each triangle. "T" = bottlenose dolphin, *Tursiops truncatus*; "U" = unidentified whale.

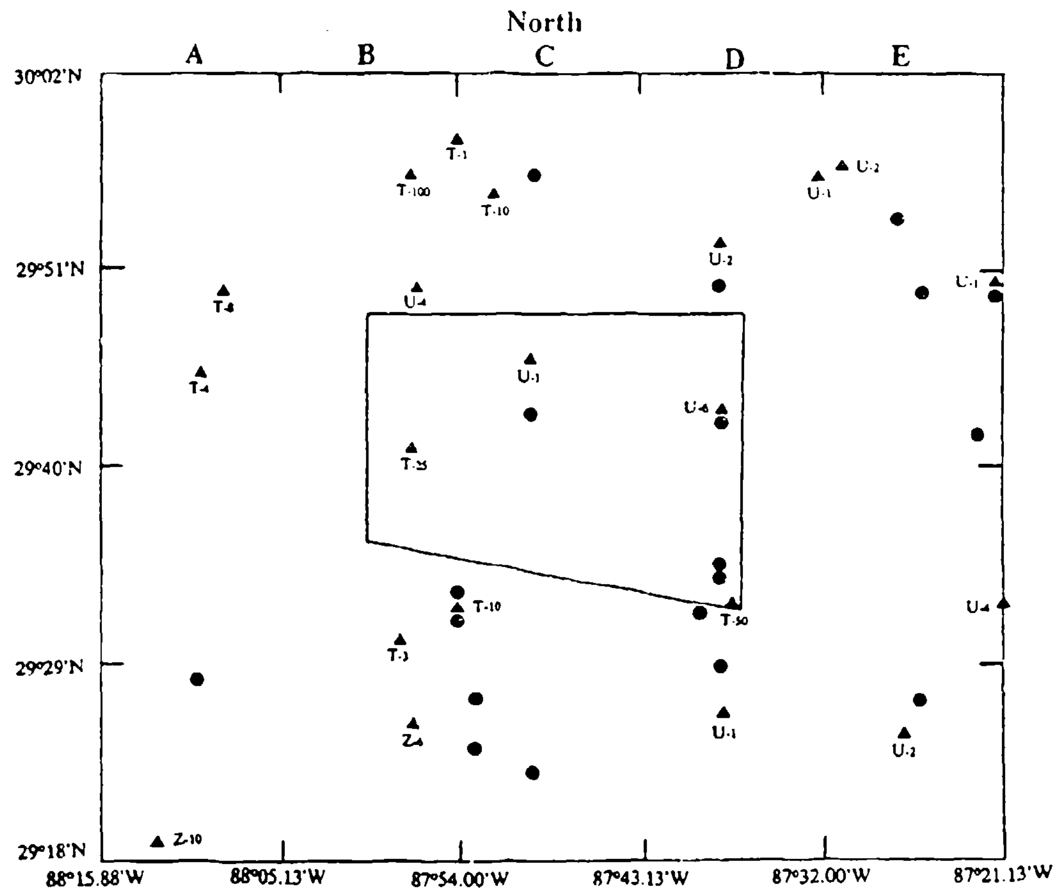


Fig. 24 — Location of all sea turtles (circles) and cetaceans (triangles) observed in the *Empress II* study area and operating area during December 1991. A circle indicates the sighting of one sea turtle. The number of whales counted or estimated at each location is shown next to each triangle. "T" = bottlenose dolphin, *Tursiops truncatus*; "Z" = one of the beaked whales, F: *Ziphiidae*; "U" = unidentified whale.

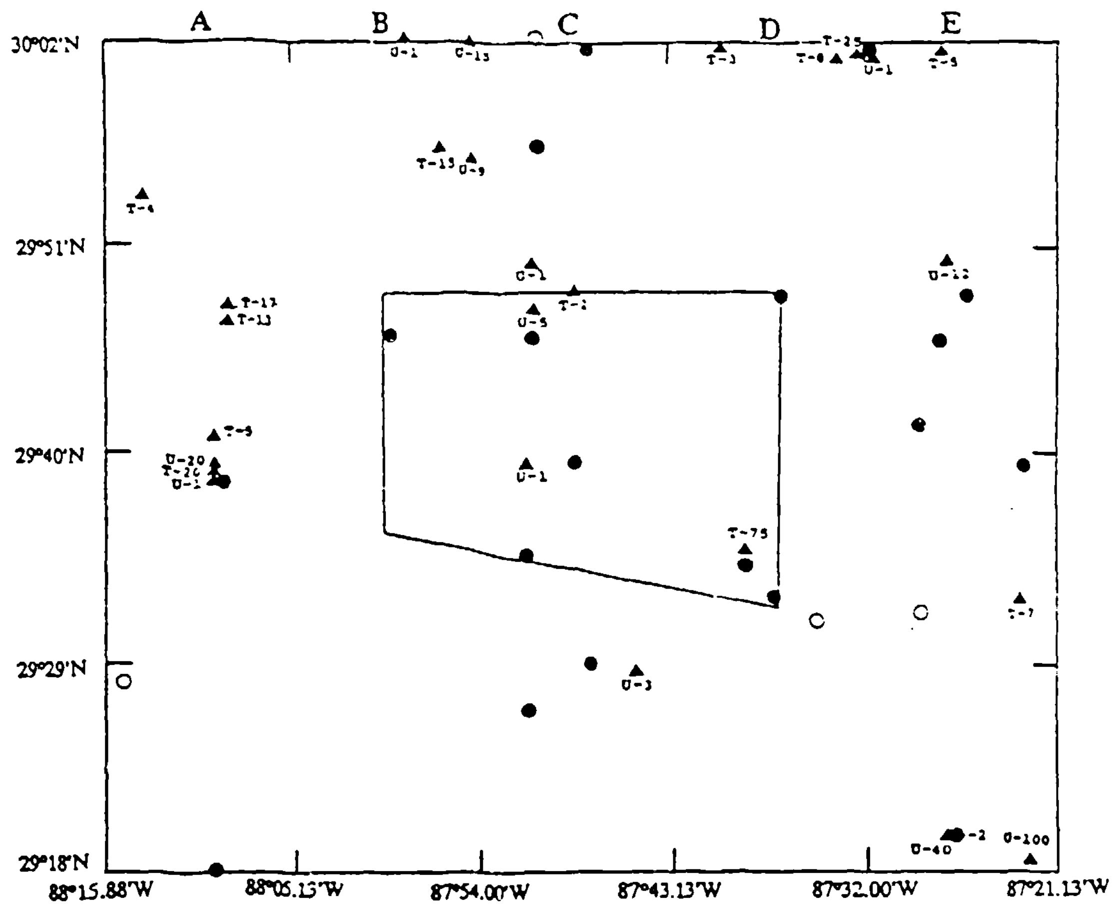


Fig. 25 — Location of all sea turtles (circles) and cetaceans (triangles) observed in the *Empress II* study area and operating area during January 1992. An open circle indicates a leather back turtle (*Dermochelys coriacea*) sighting, and a closed circle indicates the sighting of one of the other turtle species. The number of whales counted or estimated at each location is shown next to each triangle. "T" = bottlenose dolphin, *Tursiops truncatus;* "D" = one of the other dolphins; "U" = unidentified whale.

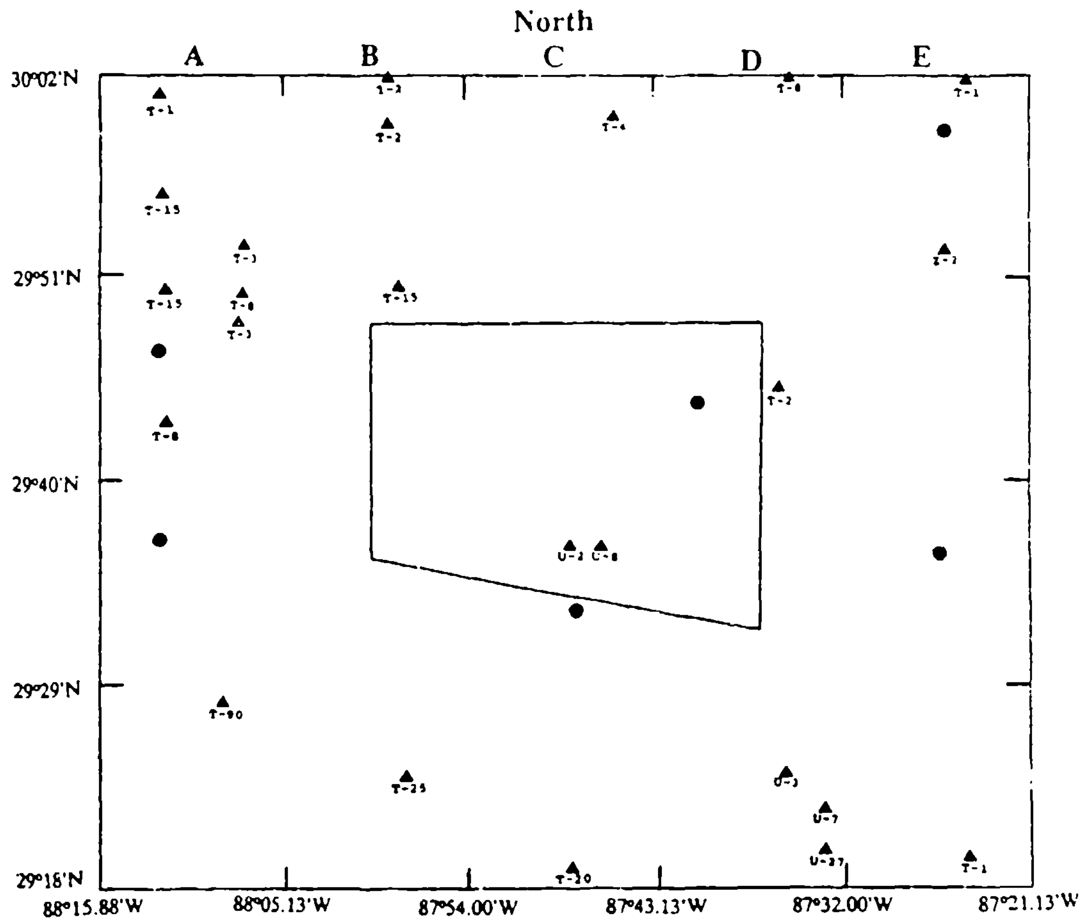


Fig. 26 — Location of all sea turtles (circles) and cetaceans (triangles) observed in the *Empress II* study area and operating area during February 1992. A closed circle indicates the sighting of one sea turtle. The number of whales counted or estimated at each location is shown next to each triangle. "T" = bottlenose dolphin, *Tursiops truncatus*; "U" = unidentified whale.

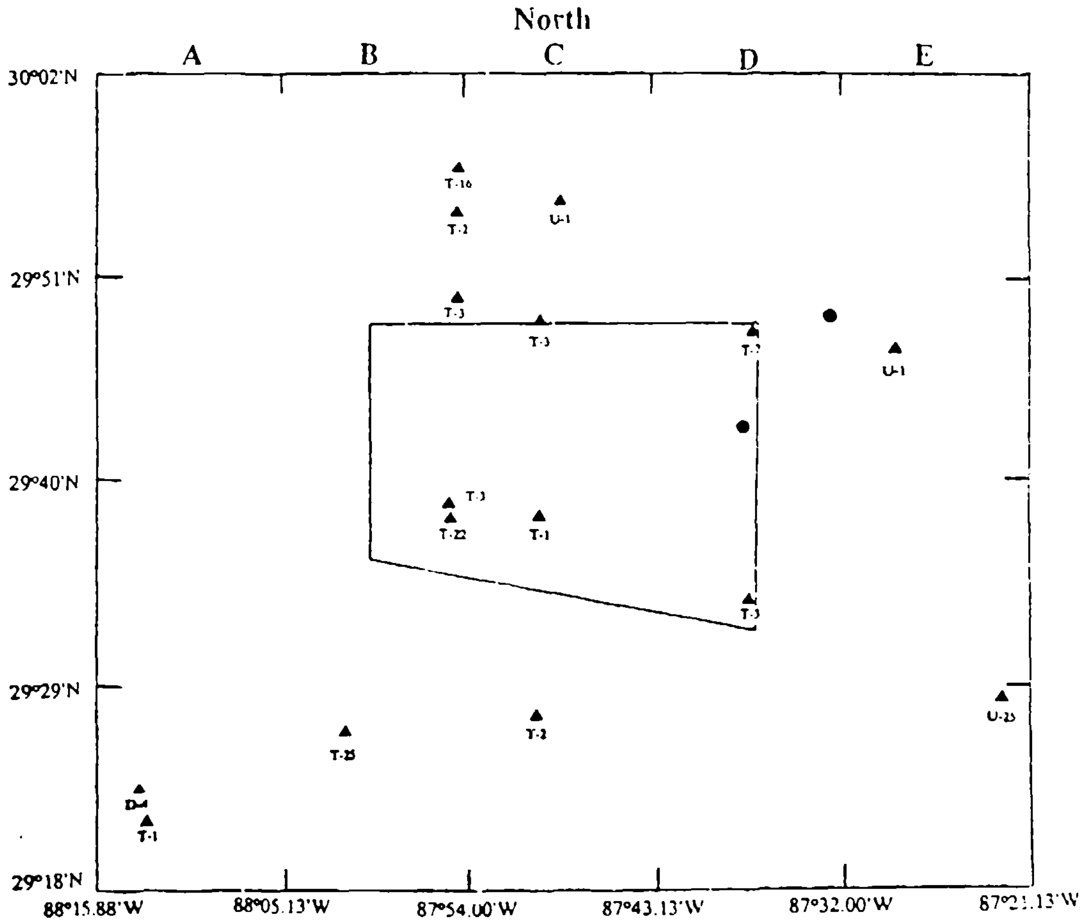


Fig. 27 — Location of all sea turtles (circles) and cetaceans (triangles) observed in the *Empress II* study area and operating area during March 1992. A closed circle indicates the sighting of one sea turtle. The number of whales counted or estimated at each location is shown next to each triangle. "T" = bottlenose dolphin, *Tursiops truncatus;* "D" *Delphinidae* (Family of dolphins); "U" = unidentified whale.

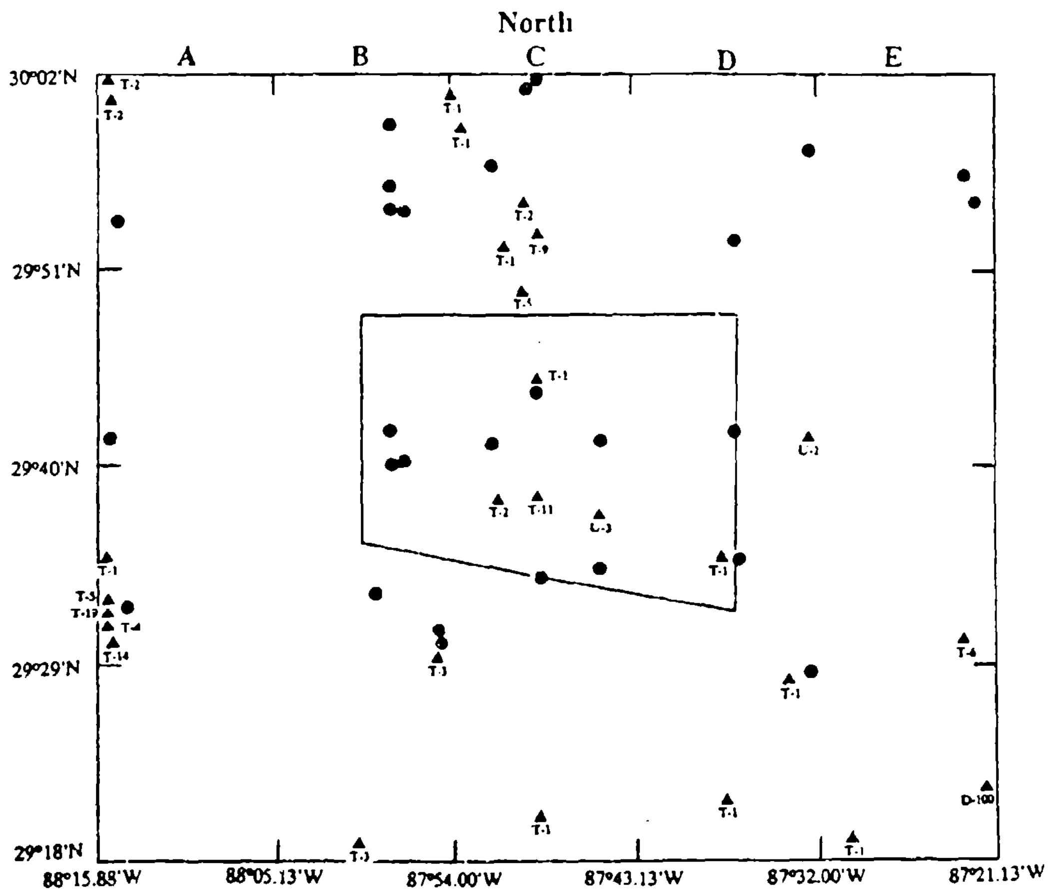


Fig. 28 — Location of all sea turtles (circles) and cetaceans (triangles) observed in the *Empress II* study area and operating area during April 1992. A closed circle indicates the sighting of one sea turtle. The number of whales counted or estimated at each location is shown next to each triangle. "T" = bottlenose dolphin, *Tursiops truncatus*; "D" = *Delphinidae* (Family of dolphins); "U" unidentified whale.

APPENDIX A
ESTIMATES OF MARINE MAMMAL ABUNDANCE IN THE *EMPRESS II* STUDY AREA: NOVEMBER 1991-APRIL 1992

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SUMMARY AND RESULTS

Based on a total of 83 sightings over the study period, the estimated average abundance of sea turtles in the study area for the study period is 57.34 (SE = 15.31). For cetaceans (whales and dolphins), based on 116 total sightings, and an average group size of 10.12, the estimated average abundance is 802.80 (SE = 208.56). These estimates represent the estimated average abundance for the 30 survey days in the study period.

Abundance estimates for cetaceans and chelonids were computed for each month (Tables A1 and A2). The monthly estimates can be thought of as estimates of the average abundance for the 5 days flown each month. For both cetaceans and turtles, the distance data were pooled from all survey days to obtain estimates of sightability. Variability in the estimates from month to month can be attributed to variation in number of sightings and variation in mean group size. Due to limited data, I was not able to compute standard errors for the monthly abundance estimates.

I found no evidence of size-bias in either the cetacean or chelonid data. That is, it appears that group size did not influence detectability in either case. For both turtles and cetaceans, the line transect detection functions exhibited unusual shapes. This could be due to pooling the distance data over a large number of observers and sighting conditions, or observers scanning away from the transect line.

Table A1 — Estimated Monthly Cetacean Abundance. The abundance estimates represent an estimate of the average abundance for the 5 days flown during that month.

Month/Year	Number of Sightings	Mean Group Size	Abundance Estimate
Nov/91	16	8.63	565.8
Dec/91	17	14.18	987.7
Jan/92	26	14.27	1520.2
Feb/92	22	11.73	1057.3
Mar/92	12	7.83	385.0
Apr/92	23	3.13	295.0

Table A2 — Estimated Monthly Turtle Abundance

Month/Year	Number of Sightings	Mean Group Size	Abundance Estimate
Nov/91	8	1.00	32.8
Dec/91	17	1.00	69.6
Jan/92	23	1.04	98.0
Feb/92	5	1.00	20.5
Mar/92	2	1.00	8.2
Apr/92	28	1.00	114.7

The line transect aerial surveys appear to be adequate for monitoring population trends. Of course, as in other marine mammal surveys. these abundance estimates neglect submerged creatures.

DATA USED IN THE ANALYSIS

I took individual transect lengths to be 81.5 km, so each survey day yielded $5 \times 81.5 = 407.5$ km of transect. For the entire study period, this yields $30.5 \times 81.5 = 12{,}225$ km of transect. The study area was 7,555.05 km^2.

Each observation was placed into 1 of 3 categories based on the observer's classification: turtles, whales, or dolphins. For the entire study period, there were 83 turtle sightings, 103 dolphin sightings, and 13 whale sightings.

I assumed a maximum sighting angle of 65°, an average flying altitude of 0.230 km, and I truncated all distance data beyond 0.650 km. I assumed that there was a strip of half-width 0.107 km beneath the vessel that was unobservable.

I omitted a very few (<5) observations where the sighting angle or group size data were missing, or where the data recorder indicated that the data were of questionable quality.

For a very few observations (<5%) of delphinids, group sightings were broken down by juvenile and adult. There were insufficient data on juvenile sightings to obtain reliable estimates of age ratios. The number of adults and number of juveniles sighted in a group were summed to obtain one group size. In those instances where a range was given for group size, I used the midpoint of that range.

DATA ANALYSIS

Testing for Size-bias

Line transect sampling assumes that the probability of sighting an item from the transect line is a function of the item's perpendicular distance from the transect (Burnham et al. 1980). However, when species tend to form groups, there is a possibility that the number of individuals in the group, or group size, influences sightability. In this case, typically, large groups have a greater chance of detectability than smaller groups. If this bias is not accounted for, overestimation of abundance can occur (Drummer and McDonald 1987).

I employed the bivariate sighting functions of Drummer and McDonald (1987) to perform a formal test for size-bias as they define it. Their models contain a size-bias parameter that can be estimated and subsequently tested for statistical significance. To fit the functions, the raw distance data were shifted back to the origin by subtracting 0.107 km from the sighting distance. This linear transformation does not affect the test for size-bias, and also gives some indication as to the shape of the detection function.

I did separate analyses for the turtle and cetacean (dolphins and whales combined) data. I used all of the data for the entire study period in this analysis, thus, for turtles, $n = 83$ and for cetaceans, $n = 116$. In the cetacean data, group sizes ranged from 1 to 100 individuals; whereas, there were never more than 2 turtles in a group, and this occurred infrequently.

The results of these analyses indicated no significant size-bias for either group. For the turtle data, size-bias is not really a concern given the small variability in group size. For these data, estimates of the size-bias parameter were, based on my experience, nonsensical and not statistically different from 0.0.

For the cetacean data. in which group sizes varied significantly, size-bias was a potential concern. However, based on estimates from the bivariate detection functions, none of the four estimates of the size-bias parameter were significantly different from 0.0 with all p-values > 0.50.

Results of these analyses are subject to some doubt, however, due to the poor fit of the detection functions. The bivariate detection functions are monotone decreasing in distance, and graphical analyses of the distance data indicated that may not be true. I, therefore, proceeded with other analyses to check for size-bias.

For the cetacean data, the correlation between distance and group size was < 0.1358 and was statistically insignificant ($p = 0.4921$). Although the lack of such a correlation does not necessarily imply a lack of size-bias (Drummer and McDonald 1987), a significant correlation between distance and group size would indicate a size-bias problem. A scatterplot indicates no obvious relationship between group size and distance (Fig. A1).

Using the quartiles of the distance distribution to define four strata, one poststratified the data by distance from the transect and computed the mean group size within each distance strata. I compared these four means with ANOVA. There was no significant difference between these means ($p = 0.5837$). If size-bias were present, I would expect mean group size to increase as distance from the transect increased, but that is not the case (Table A3).

In summary, I concluded that there was no size-bias in either the cetacean or chelonid data, and used the respective observed mean group sizes as estimates of the true mean group size.

FITTING THE DETECTION FUNCTIONS

For both the cetacean and turtle data, the distance data from the entire study period were pooled to fit a detection function to each set of data. I compared distance distributions between observers and also between months, but could discern no clear differences, and concluded pooling was both reasonable and necessary. Figure A2 displays histograms of the cetacean and turtle distance data, and Fig. A3 displays nonparametric estimates of the underlying probability density functions obtained with kernel estimators (Silverman 1986), which can be thought of as smoothed histograms.

Table A3 — Size-Bias Test for Cetacean Data

Distance Strata (x = distance)	n	Mean Group Size
107 m < x <207 m	2	9.11
207 m < x <328 m	29	14.54
328 m < x <392 m	29	6.92
392 m < x <650 m	29	9.16

From Figs. A2 and A3, it seems clear that detection is not maximized directly on the minimum sight line (0.107 km), but rather reaches its maximum at some distance out from the sight line. Traditional line transect estimators assume that the distribution peaks at the transect (distance = 0.0) and declines thereafter, and that the probability of detection on the transect = 1.0. These data are left truncated at 0.107 km, but it does not appear that either detection function is maximized at that point. This may be due to pooling across the various factors, or could be due to a natural tendency of the observers to scan out from the vessel.

Let f(x) denote the probability density function of perpendicular sighting distances. Quang and Lanctot (1991) proposed a procedure that could be used when this distribution is unimodal, but the mode does not occur at the origin, or in this case 0.107 km. Instead, their procedure assumes that the probability of detection = 1.0 at some point, d, the mode of the density function f(x). The line transect density estimator requires the estimation of f(d) rather than the more familiar f(0) (Burnham et al. 1980). Note that rough estimates of d and f(d) can be made from Fig. A3, although the plot resolution is slightly misleading.

Quang and Lanctot proposed using the truncated Beta distribution as a density function and provided a computer program, AERTRAN, capable of fitting this distribution. The truncated Beta can assume a wide variety of shapes and can easily accommodate the shapes exhibited in Fig. A3. I used the program AERTRAN to fit, via maximum likelihood, truncated Beta distributions to both the cetacean and turtle distance data. From these fits, I obtained estimates of d, f(d), group density (D_g) and the standard error of D_g. Model adequacy was judged by goodness-of-fit tests.

ABUNDANCE ESTIMATES

When the individual data points consist of groups, the estimated group density D_g is multiplied by the estimated mean group size, y-bar, to obtain the estimated density of individuals (d_i). For both cetaceans and chelonids, abundance estimates and variance estimates were computed as follows. Let:

n = the number of independent sightings for the time period of interest,

d = the distance at which sightability = 100%,

$\hat{f}(d)$ = the estimated value of the detection function at the estimated mode d, as described in Quang and Lanctot (1991).

L = total transect length surveyed for time period of interest,

y-bar = observed mean group size for time period of interest, and

A = size of the study area (7555.05 km^2).

The estimated group density is given by $\hat{D}_g = \frac{n \cdot \hat{f}(d)}{2 \cdot L}$, with the estimated density of individuals given by $\hat{D}_i = \hat{D}_g \cdot y - \text{bar}$. The estimated total abundance is obtained by multiplying the estimate of individual density by the size of the study area, A.

AERTRAN obtains estimates of the sampling variance of the group density estimate via bootstrapping. I used individual survey days as replicates for the bootstrapping algorithm. I believe this to be appropriate because the largest source of variation in the sighting data seemed to be the number of sightings on the different survey days. The estimated individual density is the product of two independent random variables, so standard methods for estimating this variance were used.

RESULTS

Goodness-of-fit tests indicated possible model inadequacy (Table A4). However, the crucial parameter to be estimated is f(d), and estimates of f(d) from the kernel estimators (Fig. A3) and truncated Beta model were comparable. Also, in each case, one category made a very large contribution to the goodness-of-fit test statistic. I decided to use the AERTRAN results because the fits seemed reasonable, and AERTRAN provides a robust estimate of sampling variance.

Table A4 — Goodness-of-Fit Tests for Truncated Beta Model

Cetaceans		
Distance Category	Observed Count	Expected Count
0.107–0.1875 km	10	15.4
0.1875–0.2625 km	25	19.7
0.2625–0.3375 km	27	22.3
0.3375–0.4125 km	27	21.7
0.4125–0.4875 km	5	18.0
0.4875–0.5625 km	12	10.0
0.5625–0.6500 km	10	6.6
Chi-square statistic = 16.75, with 4 df, yields p = 0.001.		
Turtles		
Distance Category	Observed Count	Expected Count
0.107–0.1875 km	11	15.3
0.1875–0.2625 km	19	16.6
0.2625–0.3375 km	26	16.4
0.3375–0.4125 km	13	14.1
0.4125–0.4875 km	0	10.5
0.4875–0.5625 km	8	6.6
0.5625–0.6500 km	6	3.5
Chi-square statistic = 19.84, with 4 df, yields p = 0.001.		

Table A5 — Computations to Obtain Overall Density and Abundance. Estimates are Detailed. Total Transect Length Used to Obtain These Estimates is 12,225 km.

All density estimates are per km^2.
d = estimated distance at which the probability of detection = 1.0.
f(d) = the estimated value of the density function at the point d.
SE = standard error of estimate.

Cetaceans					
n	y-bar	d	f(d)	D_g(SE)	D_i(SE)
116	10.12	0.42 km	2.21	0.0105(0.002)	0.1063(0.027)
The estimated average number of individuals is 7555.05 $km^2 \times 0.1063$ km^2 = 802.80 with a standard error of 208.56.					
Turtles					
n	y-bar	d	f(d)	D_g(SE)	D_i(SE)
83	1.012	0.38 km	2.21	0.0075(0.002)	0.0076(0.002)
The estimated average number of individuals is 7,555.05 $km^2 \times 0.0076$ km^2 = 57.34, with a standard error of 15.31.					

Table A6 — Monthly Abundance and Density Estimates are Detailed. Transect Length Used to Obtain These Estimates is 2037.5 km. Note that the Same d and f(d) are Used for all Estimates.

Cetaceans							
month/year	n	y-bar	d	f(d)	D_g	D_i	N_i
11/91	16	8.63	0.42 km	2.21	0.0087	0.075	565.8
12/91	17	14.18	0.42 km	2.21	0.0092	0.131	987.7
01/92	26	14.27	0.42 km	2.21	0.0141	0.201	1520.2
02/92	22	11.73	0.42 km	2.21	0.0119	0.140	1057.3
03/92	12	7.83	0.42 km	2.21	0.0065	0.051	385.0
04/92	23	3.13	0.42 km	2.21	0.0125	0.039	295.0
Sea Turtles							
month/year	n	y-bar	d	f(d)	D_g	D_i	N_i
11/91	8	1.00	0.38 km	2.21	0.0043	0.0043	32.8
12/91	17	1.00	0.38 km	2.21	0.0092	0.0092	69.6
01/92	23	1.04	0.38 km	2.21	0.0125	0.0129	98.0
02/92	5	1.00	0.38 km	2.21	0.0027	0.0027	20.5
03/92	2	1.00	0.38 km	2.21	0.0011	0.0011	8.2
04/92	28	1.00	0.38 km	2.21	0.0152	0.0152	114.7

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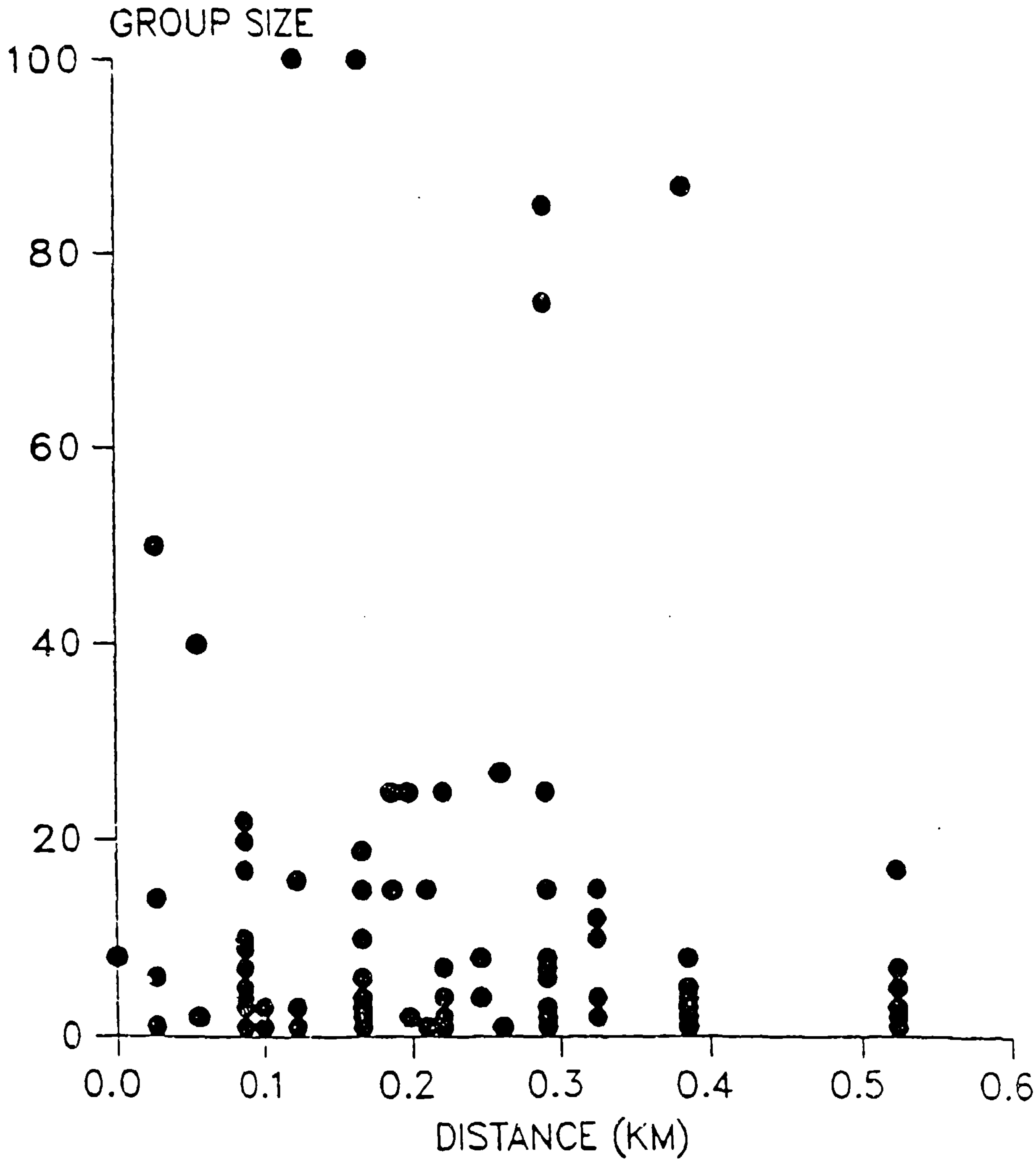

Fig. A1 — Group size vs. distance for all cetacean data

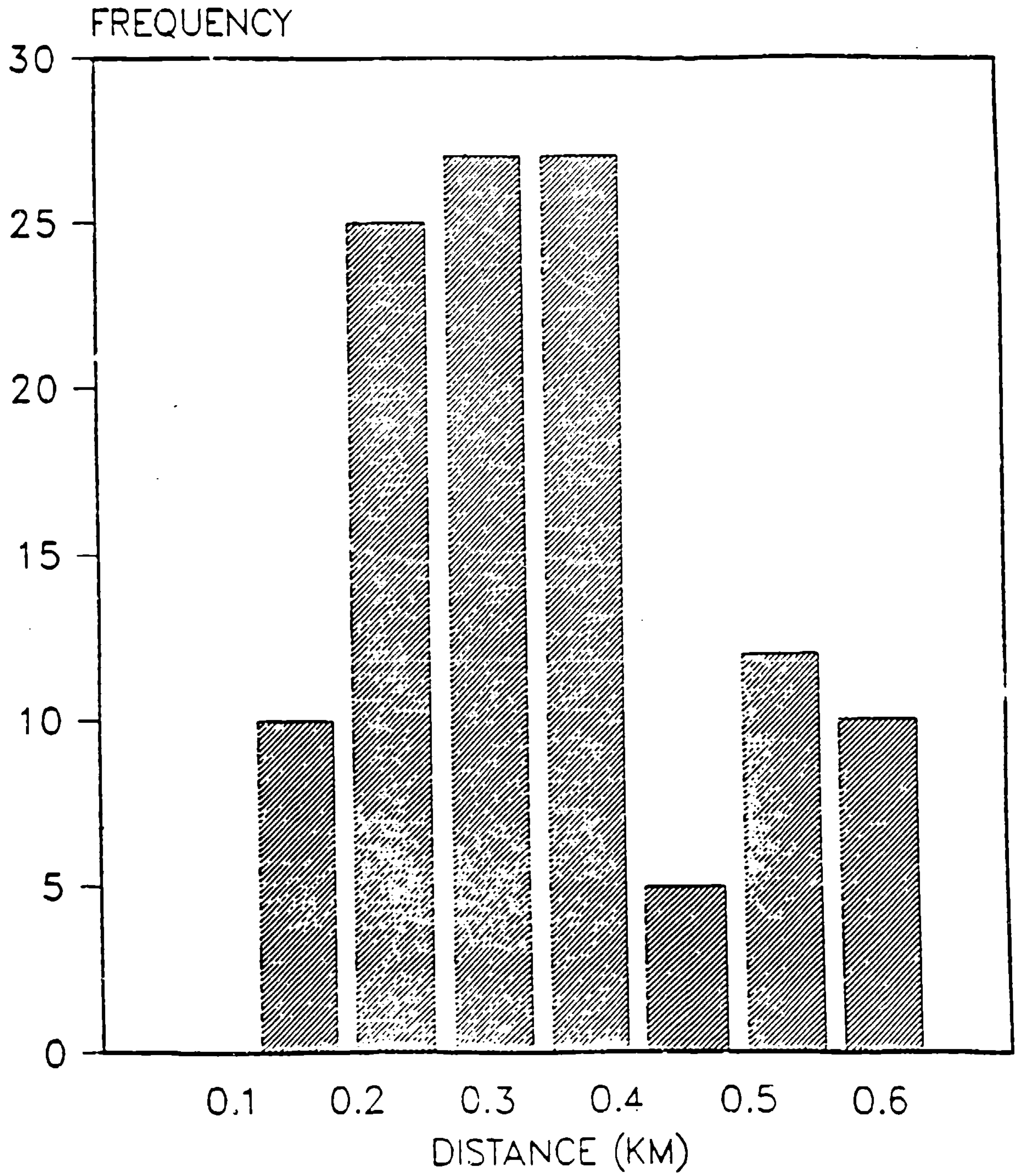

Fig. A2A — Histogram of sighting distances cetacean data

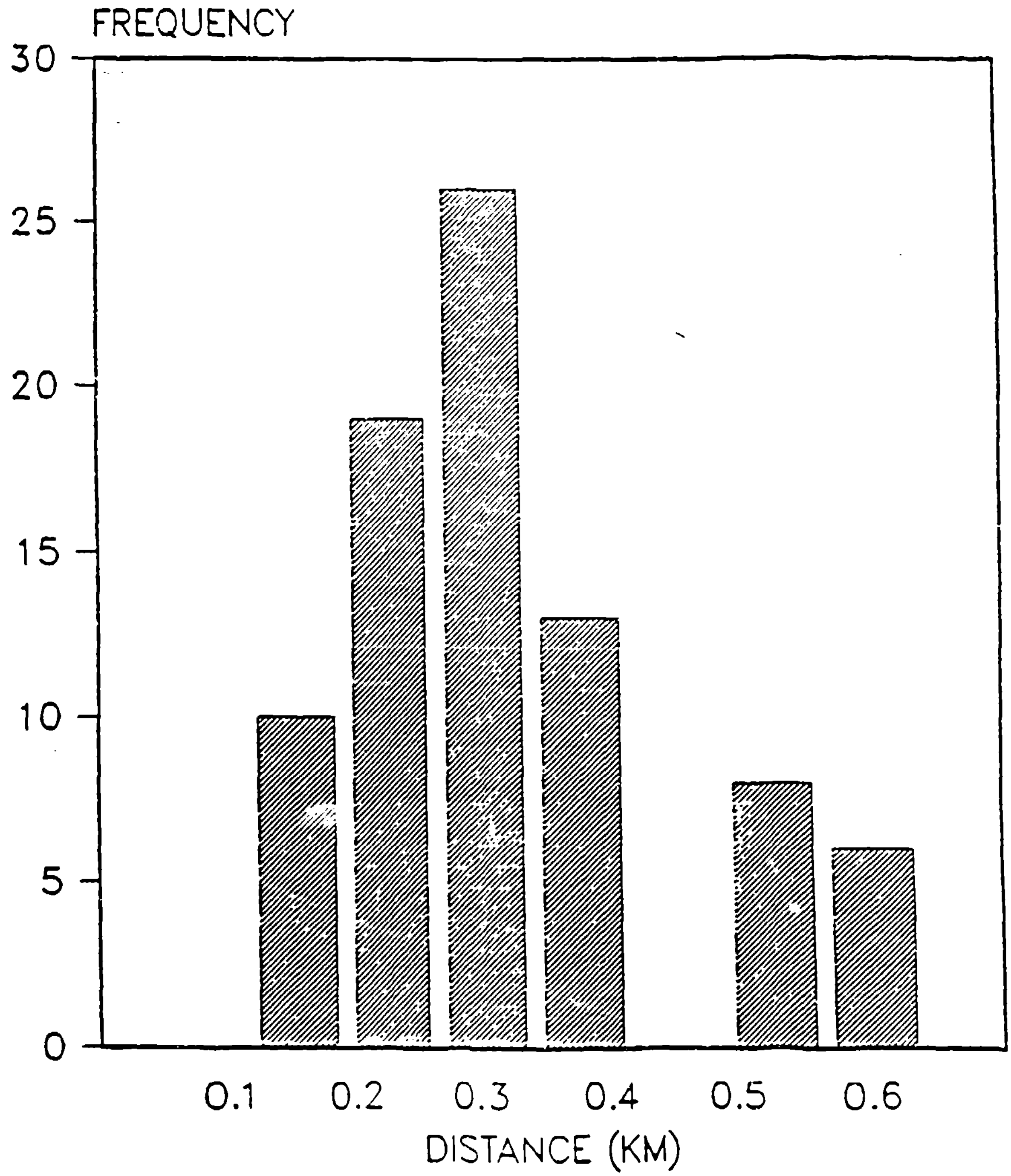

Fig. A2B — Histogram of sighting distances turtle data

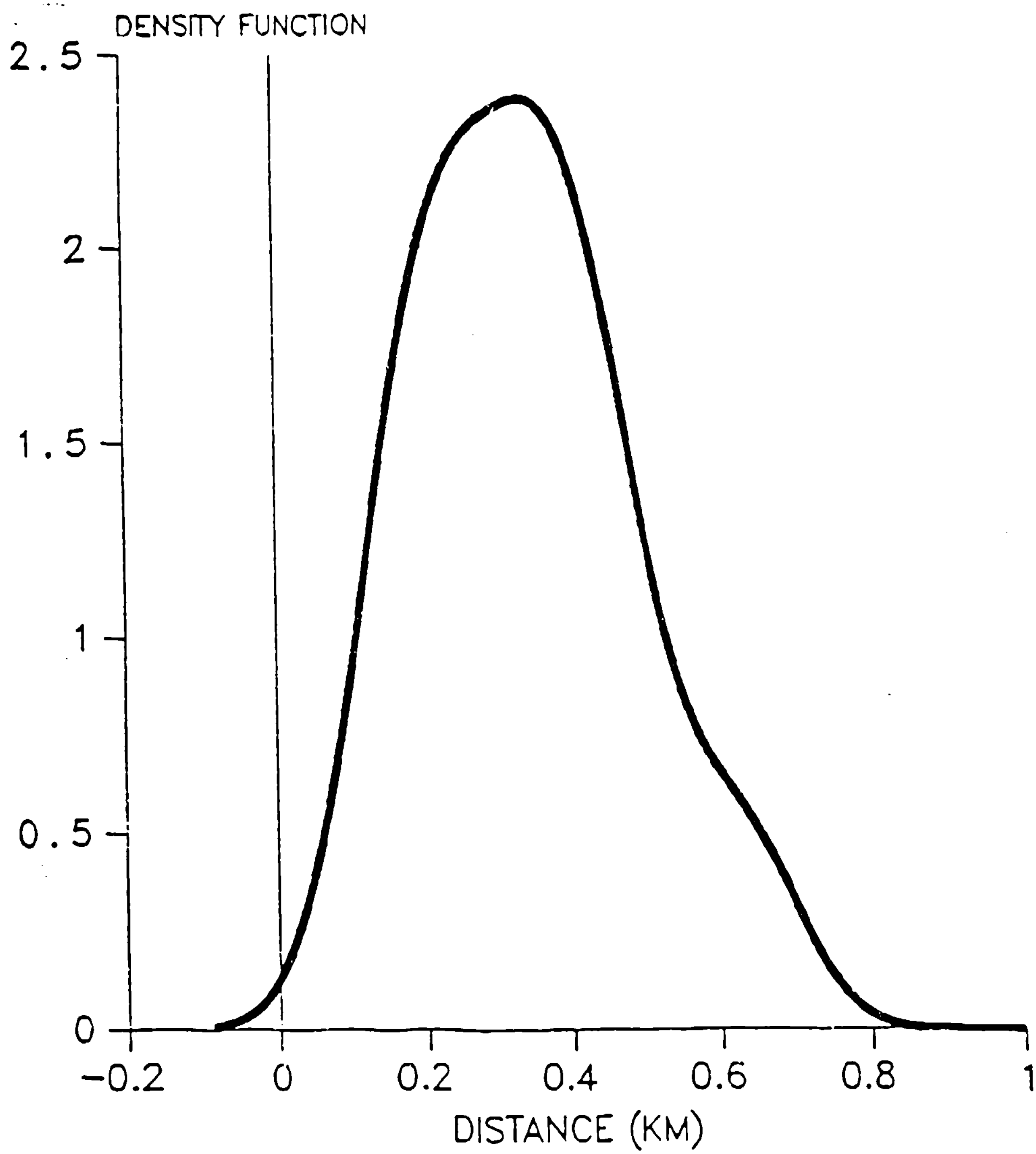

Fig. A3A — Kernel estimate of density function cetacean data

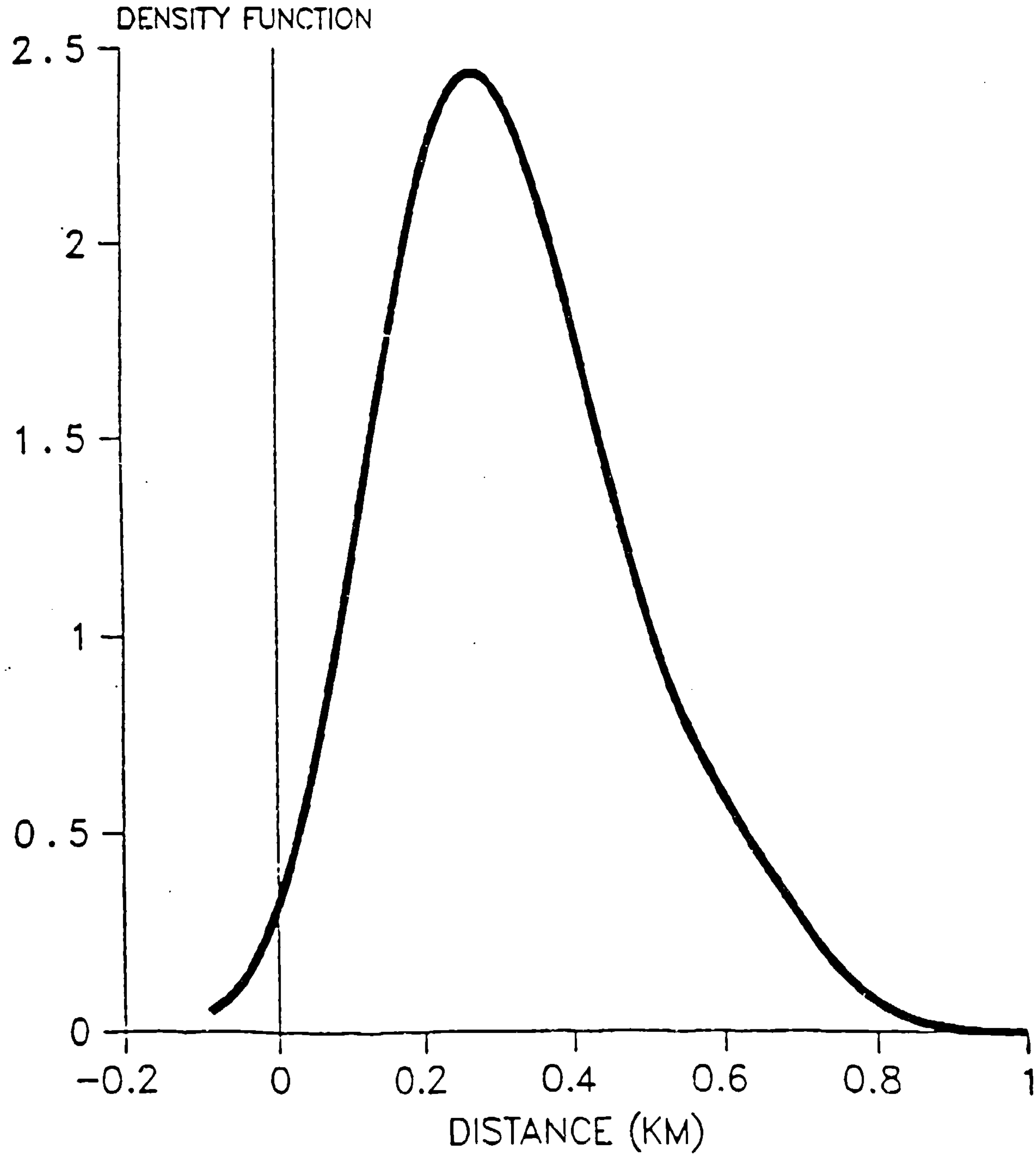

Fig. A3B — Kernel estimate of density function turtle data

APPENDIX B
DATA SUMMARY

Table B1 — Data Summary for Individual Survey Days

Sea Turtles

Date	Independent Sightings	Mean Group Size
1992/02/11	1	1
1992/03/12	1	1
1992/03/14	1	1
1992/04/09	5	1

Date	Independent Sightings	Mean Group Size
1992/04/22	1	1
1992/04/23	2	1
1992/04/24	15	1
1992/04/29	5	1

Table B2 — Data Summary for Individual Survey Days

All Cetaceans

Date	Independent Sightings	Mean Group Size	Date	Independent Sightings	Mean Group Size
1991/11/12	1	1.0000	1992/01/21	5	25.4000
1991/11/13	4	4.2500	1992/02/02	1	15.0000
1991/11/14	2	2.0000	1992/02/03	5	13.8000
1991/11/15	1	85.0000	1992/02/10	4	10.0000
1991/11/22	8	3.8750	1992/02/11	6	18.3333
1991/12/16	1	2.0000	1992/02/12	6	4.0000
1991/12/17	10	1.0000	1992/03/12	2	25.0000
1991/12/18	2	1.5000	1992/03/14	1	1.0000
1991/12/22	3	18.3333	1992/03/26	9	4.7778
1991/12/26	1	1.0000	1992/04/09	6	2.3333
1991/01/05	1	75.0000	1992/04/22	2	1.0000
1992/01/06	14	6.0714	1992/04/23	2	3.5000
1992/01/07	4	9.7500	1992/04/24	12	3.9167
1992/01/15	2	22.5000	1992/04/29	1	2.0000

Sea Turtles

Date	Independent Sightings	Mean Group Size	Date	Independent Sightings	Mean Group Size
1991/11/12	1	1.0	1991/12/26	2	1.0
1991/11/13	1	1.0	1992/01/05	5	1.0
1991/11/15	3	1.0	1992/01/06	10	1.0
1991/11/22	3	1.0	1992/01/07	4	1.0
1991/12/16	1	1.0	1992/01/15	2	1.0
1991/12/17	6	1.0	1992/01/21	2	1.0
1991/12/18	3	1.0	1992/02/03	1	1.0
1991/12/22	5	1.0	1992/02/10	2	1.0